PRIZE ESSAY

ON THE

PREVENTION OF THE SMOKE NUISANCE.

BY

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AUTHOR OF THE "ESSAY ON THE COMBUSTION OF COAL, CHEMICALLY AND PRACTICALLY CONSIDERED."

THE SPECIAL GOLD MEDAL WAS AWARDED FOR THIS ESSAY, BY THE SOCIETY FOR THE ENCOURAGEMENT OF ARTS, MANUFACTURES, AND COMMERCE.

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INTRODUCTION.

EXTRACT FROM THE PROCEEDINGS OF THE LONDON SOCIETY FOR THE ENCOURAGEMENT OF ARTS, MANUFACTURES, AND COMMERCE.

"SPECIAL PRIZE,

"For the best essay on the means of *preventing the nuisance of smoke* arising from fires and furnaces; treating the subject practically; *reviewing the various plans* which have been put forth as remedies; with the experience of *their success or failure;* and the results of their adoption as to *expense or economy* in erection and in working. The *legislative measures* necessary for the prevention of the nuisance, and the *causes of the failure* of the local acts for its suppression, should also form part of the essay. Twenty-five pounds, or a gold medal of the same value.

By Order,

"Society's House, Adelphi, London." P. LE NEVE FOSTER, SECRETARY.

The following is the order in which the several heads for consideration are here treated:—

Section

1. On the question generally considered, of preventing the smoke nuisance.
2. Of the various plans which have been put forth as remedies.
3. Of the plans which affect to burn smoke by bringing it into connexion with *incandescent* fuel.
4. Of the plans which rely on the use of *hot air.*
5. Of the plans which rely on the use of *mechanical applications.*
6. Of effecting combustion, and avoiding the formation of smoke, by due attention to the *introduction of atmospheric air.*
7. Of the expense or economy of the proposed plans, in erecting and working.
8. Of the nature and properties of smoke.
9. Of the practical application of the principles here explained, and the proposed remedial measures.
10. Of legislative measures, applied to the prevention of the smoke nuisance.

It will here be seen that this order is in conformity with the above notice of the Council of the Society of Arts. The only disadvantage of this arrange-

ment is, that it rendered repetitions occasionally necessary, each head becoming, as it were, a separate subject.

In this essay no new theory is offered—no new view of the nature of combustion is attempted, neither is any inference drawn that is not in strict accordance with the highest chemical authorities, and with the results of successful experience.

PRIZE ESSAY

ON THE

PREVENTION OF THE SMOKE NUISANCE.

SECTION I.

ON THE QUESTION OF PREVENTING THE NUISANCE OF SMOKE.

ESSAYS on the prevention of the nuisance of smoke cannot fail to elicit much useful information, and are especially called for at the present time, not only on account of the prevailing misapprehensions respecting the cause of smoke, but of the erroneous impression that, to abate the nuisance, it is only necessary that the smoke should be "*burned*," although no attempt has been made to prove that it is *combustible*.

This latter misapprehension manifestly influenced those who prepared the late act (16 & 17 Vict., chap. 128), seeing that its compulsory clauses require that "every furnace shall, in all cases, be constructed or altered so as to *consume or burn the smoke* arising from such furnace;" a condition which practically involves an impossibility; and, chemically considered, is at variance with all authority, and incapable of proof.

We here see the necessity of examining the subject scientifically, and *pari passu* with that of its practical application. In truth, we cannot make a single step in the *practical* inquiry except by the aid, and in conformity with, *chemical* laws; which, in this case, are the mere expression of the processes of nature. The observations of his Royal Highness Prince Albert, in his late address at Birmingham, on the "Connexion between Science and Art," are peculiarly in point in reference to the subject under consideration, and the prevailing neglect of chemistry in the construction of furnaces:—

"In all our operations, whether agricultural or manufacturing, it is not *we* who operate, but the *laws of nature* which we have set in operation. It is, then, of the highest importance that we should *know these laws, in order to know what we are about*, and the reason why certain things are, which occur daily under our hands, and what course we are to pursue with regard to them. Without such knowledge we are condemned to one of three states: either we merely go on to do things just as our fathers did, and for no better reason than because they did them so—or, trusting to some personal authority, we adopt at random the recommendation of some specific in a speculative hope that it may answer; or, lastly, we ourselves improve upon certain processes. From none of these can we hope for much progress. But these laws of nature—these divine laws—are capable of being discovered and understood, and of being taught and made our own. This is the task of *science;* and whilst science discovers and teaches those laws, *art* teaches their application."

We have here then to examine, First, The laws of nature which control the process of combustion: Secondly, How, practically, they influence the operations in the furnace. To begin by considering how a nuisance may be abated, before defining in what it consists, would be seeking for a remedy before understanding the character of the disease to which it was to be applied.

The mere fact of a dark cloudy mass issuing from a chimney-stack conveys no idea of the bodies of which it is composed. Common observation would suggest that smoke must be merely a part of the coal which had passed away unconsumed, and, therefore, that nothing was required but the adoption of some means by which its combustion might be effected. A brief examination, however, soon satisfies us that what passes away is a compound of numerous other bodies. What these are, therefore, manifestly calls for inquiry.

At a time when all dark-coloured, vapoury matter was called smoke, and when to *burn a body* was synonymous with saying it was *utterly destroyed*, an inquiry, such as is now called for, could not have appeared necessary. Within the last half century chemistry has thrown new lights on the subject. We now know that what passes away, though invisible, has but changed its form and appearance, and as much demands attention as that which, from its colour, comes more immediately within the scope of our senses. It has been proved that the supposed homogeneous cloud, called smoke, consists both of *solid and gaseous, simple and compound* bodies—the characteristics of which, although now thoroughly understood, were, even within our own memories, but little known.

Looking at the numerous theories of the present day, and the confusion which prevails on the subject, it is manifest that a correct definition of the term smoke, and the ascertaining the distinction between *gas and smoke*, is absolutely necessary as a preliminary step in an inquiry as to how either should be dealt with. Proceeding in this way we are practically led to this distinction, that the vapour called *gas* is generated from the coal by the application of heat; and that *smoke* is the products which result from the process towards combustion of those vapours, whether perfectly or imperfectly effected. The advocates of the new smoke-burning theory assert, that smoke is *an original formation*, and that it proceeds *direct from the fuel before* the process of combustion has even commenced. When pressed, however, to explain the distinction between *gas* and what they call *smoke*, instead of describing its

ingredients or defining their properties, they merely refer to the fact of the coloured vapours which issue direct from the coal, either in the furnace, the house grate, or the retort. In this way practical men are led astray, and their efforts misdirected. They are told that smoke, necessarily, must be formed. That it consists of tar, tar vapour, and other compounds, and that some means are absolutely necessary to *raise these compounds to the required temperatures* for ignition and combustion.

Among the publications on this head may be taken one as a type of a numerous class of the most recent on the smoke nuisance, elaborately prepared and read before the Society of Arts, and inserted in their Journal, January 19th, 1855. In that paper it is stated that, " In the furnace, smoke is formed *from the fresh fuel*:—it passes to the bridge when it meets with a supply of air, and if the furnace be hot enough to supply the *initial heat*, it—that is, the smoke,— will ignite and be consumed to all intents and purposes." No explanation is given of what is meant by " initial heat,"—the term being here unintelligible and inapplicable.

Again,—" Smoke can be consumed; by that is meant that the *gas, vapours, smoke, or whatever else it may be called* which the *constables* of the metropolitan police would call smoke, can be consumed." This very loose mode of expression; such incorrect use of terms, and unscientific treatment of a chemical subject; and even the reference to the *constable*, rather than the *chemical professor*, is not only behind our time, but much to be deplored. It makes confusion worse confounded, and leads to anything but a correct or practical solution of the difficulty. It is needless to add that this new theory of smoke being primarily formed from the fresh fuel, is opposed to all chemical authority. Take the following proofs.

Doctor Ure observes—" When coal is subjected in close vessels to a red heat, it gives out a vast quantity of *gas*, which being collected and purified, is capable of affording a steady light." Here we are shown that it is *gas*, and not *smoke*, that proceeds from the fresh fuel.

Peckston, in his Treatise on the Manufacture of Gas, says, " When pit coal is burnt in an open fireplace, it emits flame which is occasionally exhibited in streams of peculiar brightness. This *flame is coal gas* in a state of combustion." Here also nothing is said of the existence of smoke, as an original formation. " The flame of coal gas," he adds, " when properly managed, by allowing no more gas to pass through the burner than can be entirely consumed, *produces no smoke*." Here, the distinction between gas and smoke is clearly indicated; the former being the direct issue from the heated coal, and *before* it enters into the process of combustion; the latter, *after* it has been in the state of flame, and showing, that if properly managed there will be *no smoke to be burned*. Now this is the precise state of things, which it is desirable to bring into effect in furnace operations.

Professor Brande, speaking of coal gas, says, " Mixtures of *hydro-carbons and other gaseous* compounds are abundantly produced during the destructive distillation of coal, and the gases thus obtained are employed for the purposes of illumination." Here, from this unexceptionable authority, we learn that, not *smoke*, but hydro-carbons and other *gases*, are the direct products from coal. It would be unnecessary to say more on this smoke-formation and smoke-burning theory, were it not that it is so obstinately pressed on public notice, and even continues to be made the basis of so many patents.

In the paper above-mentioned it is further stated, that " the burning of *smoke* is the consumption of *carburetted hydrogen gas*, evolved from the fuel," thus making smoke and carburetted hydrogen gas synonymous.

The great practical and chemical error on which this new theory rests consists in this, that no distinction is drawn between those bodies which pass from the furnace, *before* and *after* they have been in the state of flame; yet this very distinction involves the whole question of what smoke is. It ignores all consideration as to the constituents of these bodies, chemically considered, and leaves us in the dark on the main point at issue, as to how the existence of smoke may be prevented.

Sir H. Davy, in his *Researches on Flame*, has given correct views of the nature of combustion; while Dalton and his successors have defined the laws by which gaseous bodies are influenced in their mutual relations. Thus, we of the present day have within our reach whatever can be required for enabling us sufficiently to comprehend the subject for all practical purposes. Under such circumstances, then, we have but ourselves to blame if we are any longer led astray by popular errors, or the theories of those who (while each asserts that he has discovered the true mode of "burning smoke") avoid all inquiry into the grounds on which their assertions are based. This, surely, is not consistent with the analytical character of the present day.

That the required search need not be evaded on the score of labour or expense, it is but necessary to refer to those few authorities which are of easy access—Dr. Ure's *Dictionary of Arts*, Brande's *Manual of Chemistry*, and Sir Robert Kane's *Elements of Chemistry*. These contain all that can be required by general readers, and to which, for that reason chiefly, references will here be confined.

In the absence of inquiry, practical men have been taught that by mere attention to the *dimensions* of furnaces and boilers complete combustion of the fuel may be effected. To avoid so grave an error, let us observe what takes place in open domestic firegrates, where *dimensions* can have no influence. On coals being thrown on a fire, much gaseous matter is seen to be evolved. This, in ordinary language, is called smoke, and although incorrect, it is not necessary when thus used in ordinary conversation to fall out with the term. When, however, the inquiry becomes one of *chemical detail*, with a scientific analysis of the constituents of the body to be examined, the subject assumes a different character. It then becomes necessary (if our meaning is to be rightly understood), that, setting aside popular idioms and impressions, we pursue the inquiry in strict accordance with recognised scientific principles and phraseology.

This coloured matter evolved from coal on an open fire, or in the furnace, is precisely what is discharged into the retorts of the gas works, and though called smoke by many, will be found to have distinct characteristics of its own, sufficient to prevent the possibility of mistake. Among these may here, in anticipation, be mentioned one, which, though generally overlooked, ought to prevent any observant person from being so led astray as to believe this evolved matter to be smoke;—namely, the utter *absence in it of visible or tangible black carbon*, which is, however, the main element of the *colouring matter*

in smoke; for, while this mass of coloured vapour is rising in profusion from the coal in the grate or the retort, if we present to it a sheet of paper, not a single atom of carbon can be collected or observed on it,—the paper remaining unsoiled. This test, however, applied to smoke, *arising from flame*, will be found to present a very different result—the paper being instantly covered with unquestionable black carbonaceous matter, as when passed across the flame of a candle.

But to proceed. After this vapour, of a dark brown or blue colour, is expelled, it passes away, *unignited*, by the chimney; or into the condensing apparatus of the gas works. In this state, its heating power and value is evidently lost, or wasted. Presently, however, in the open grate, it may be observed to become ignited, in detached places, and entering on the process of combustion in the character of flame: at other places, this flame, changing its colour from white to red, as often seen in the large flame of a tallow candle, and generating a quantity of tangible, unmistakeable smoke. Occasionally single small jets may be observed issuing with considerable force from pieces of black coal, particularly when placed in front, with a strong heat behind them. These jets are often ignited, or may be so by applying a lighted taper to them, and producing a white flame, equal in brilliancy to that of a gas burner.

Here, then, in an open fire-grate, are represented the usual varieties in the stages of perfect and imperfect combustion :—white or red flame, with or without smoke. These varieties, however, are the result exclusively of one cause, namely, the varying quantities of gas evolved, and the extent to which, in each case, they have obtained contact with the air, before their temperature had been too much reduced. From these appearances we justly infer what takes place in the furnace.

In the case of coal placed in the retorts, and the heat applied *externally*, the gaseous vapours are discharged *internally*; and though subjected to the high temperature of a red-hot retort, do not undergo either ignition or combustion: from this single reason —that *atmospheric air is expressly excluded.* In the retorts, the object is not *to burn* the evolved gas, but *to collect* and retain it for combustion elsewhere. Now, although this fact is recognised by all engineers, we nevertheless find, in furnace arrangements, the most unaccountable indifference to the one thing really needful—namely, the due supply of air, and the conditions under which it should be introduced. In many instances, indeed, the air is absolutely excluded, or its approach so impeded, that it is impossible the required quantity could obtain access. This strange proceeding can only be accounted for by inattention to the chemical conditions under which combustion is effected.

Dr. Ure states the constituents of Newcastle coal to be as follows, viz. :—

Carbon	87·952
Hydrogen	5·239
Nitrogen and oxygen	5·416
Ashes	1·393
	100

The varieties of products which may be formed out of these few constituents are numerous. Sir Robert Kane observes,—

"The products of the distillation of coal may be arranged according to the temperature at which they may be produced—namely,

1st, or lowest temperature,	solids, as napthaline, resins, and fluids with high boiling points.
2nd, or next temperature,	fluids which are very volatile.
3rd stage,	olefiant gas (bi-carburetted hydrogen).
4th stage,	light carburetted hydrogen gas.
5th, or highest temperature,	hydrogen gas."

Here we have the varieties of products into which the gaseous constituents and "ultimate elements" of coal may be resolved under the mere influence of temperature.

Professor Brande observes, on the generation of gas,—"The coal is placed in retorts kept at a bright red heat, and the volatile parts are conveyed by a tube, called the hydraulic main, into a *condensing vessel, kept cold,* by immersion in water, and in which the water, tar, ammoniacal liquor, and other *condensible vapours* are retained." Here we detect the error of considering this tar, or tar vapour, to be among the *direct products* of coal, whereas they are the results of subsequent and deliberately-performed *cooling and condensing processes.*

Doctor Ure has shown that these products had not previously existed in the coal. Speaking of Newcastle coal, he observes, that this is "incorrectly called *bituminous*, for it contains *no ready formed bitumen*, but merely *its elements*—carbon, hydrogen, and oxygen."

"If," says Professor Brande, "we consider the principal elements of coal as carbon, hydrogen, oxygen, nitrogen, and sulphur, it is obvious that they may give rise to an almost infinite variety of *secondary compounds.* Mixtures of hydro-carbons and other gaseous compounds, are abundantly produced during the destructive distillation of coal." Here we find nothing of this *smoke* as being *primarily formed.* We see, on the contrary, that these "secondary products" require a cooling and condensing process for their formation, and without which they would pass away in the vaporous state. In the *furnace*, however, where no such cooling or condensing operation could possibly take place, they are at once, and *in their gaseous form*, ready for the process of combustion, *if the due contact with the air be obtained.*

"The first operation which coals undergo," says Doctor Ure, "on being heaved into a common furnace, is distillation, attended with a great absorption of heat, and may be compared to the distillation of sulphur in refining it, for which purpose much external heat is required. But if the fumes of sulphur *or the coals* be, *after accension, or kindling, intermingled with the due quantity of atmospherical oxygen,* they will, on the contrary, *generate from the beginning their respective calorific effects.*" This is much to the point; for whatever these fumes or vapour may be, they will all, "*from the beginning*,"—meaning from their first issue from the coal—generate their respective calorific effects, if "mingled with the due quantity of air." Can we have a more instructive lesson as to the supply of air to the vapours *as they first issue from the coal*, or one more suggestive of what is required in furnace operations?

It is important, also, to observe what takes place in the gas works, as it further explains the error of assuming that tar, tar vapour, or any of the secondary formations, require the application or aid of red-hot

fuel to raise them to the temperature required for combustion—an opinion which prevails to a considerable extent, as hereafter will be shown.

Professor Brande states that these *secondary products* are the results of a cooling and condensing process. This process, however, is adopted for the sole purpose of separating the ***condensible*** from the ***incondensible*** vapours, as they first issue from the coal; the former of which, if not so separated, would become condensed in the pipes through which they had to be conveyed, and soon choke them up. It is clear, therefore, that if we enable these vapours, condensible and incondensible, at once, and "*from the beginning*," to enter into combustion, by supplying them with the necessary quantities of air, we absolutely prevent the formation or existence of such *secondary formations.* With equal propriety, indeed, might it be alleged that provision should be made in the furnace for the combustion of naphtha, chrysene, or other of the infinite variety of "secondary compounds" into which the combustible and volatile products of the coal might be reduced. Is it, then, necessary to ask if we be justified in looking to the unscientific portion of the public, who ignore all chemical authority, for setting the world right in this new theory of smoke-formation and smoke-combustion?

Apart from all chemical considerations, it appears unaccountable that, in a community so familiar with the use of coal gas for illuminating and culinary purposes, we should so long have been inattentive to it in our *furnaces.* The gas, the air, and the processes of nature are the same — similar causes produce similar effects; nevertheless, we reject in the one case what we adopt in the other. Some reason should be given for the change. The truth appears to be, that, previous to the use of coal gas for illuminating purposes, the question and process of ***combustion*** was considered one of mere abstract chemistry, in which the community at large took no interest—that they are still under the influence of popular, but unscientific errors and false theories—and that it will require a probationary term before the bulk of men become familiar with even those elementary truths with which every chemical professor is as familiar as with the rudiments, or mere alphabet, of the science.

SECTION II.

OF THE VARIOUS PLANS WHICH HAVE BEEN PUT FORTH AS REMEDIES, WITH THE EXPERIENCE OF THEIR SUCCESS OR FAILURE.

A REVIEW of such plans involves an examination ***scientifically*** considered, in reference to their respective merits;—and ***practically***, as to the results of their application. This has become the more necessary seeing that the Patentees themselves have not given any rational or sufficient explanation of the grounds on which they call for public confidence, though all insist on the superior merit of their respective inventions, claiming, not only to ***burn, consume, prevent***, or ***subdue*** the smoke, as the case may be, but to effect a considerable economy in fuel.

With reference to their success or failure, we have no means of ascertaining the truth. Several have obtained individual testimonials of successful application. These, however, on examination, were so often found to be unconnected with any known principle, that no reliable inference could be drawn from them. Not unfrequently, indeed, abundant reasons presented themselves for proving that their success had been wholly irrespective of that on which the Patentees themselves had even ostentatiously relied. Of this practice, so unworthy of any professing to be professional or scientific, a somewhat notable instance is afforded in the patent venetian blind valves of M. Prideaux, in which the valves themselves and all that is *unimportant* on the score of effecting combustion, is dwelt on with the most exaggerated attractions; while that by which the useful result is really produced, in aid of combustion, is treated with an almost studied neglect.

Again, cases of success are very often deceptive in this respect, that an apparatus which might be all-sufficient, where the wants of the steam-engine were satisfactorily supplied by moderate firing and slow combustion, would nevertheless fail, where much steam was required, and where heavy firing and large furnaces were necessary: as for instance, for the heating manufactories, or in the sugar refining operations.

As to the principles on which the several plans were alleged to be based, it cannot be expected that inventors of patent furnaces, any more than of patent medicines (mere commercial profit being, in both cases, the sole object), should be liberal in supplying information which might lead to the detection of their several fallacies. Not unfrequently, supposed inventions or real imitations are intentionally obscured by complicated details, or overlaid by useless and expensive mechanical contrivances, introduced, as well for the purpose of concealment or mystification as of justifying high charges and "Patent Right." Proof of this will hereafter be given.

To enumerate the various plans which have been put forth as remedies, in connexion with the smoke question, would here be as useless as impossible. The new cheap Patent Law brought rapidly into existence above one hundred so-called inventions, for the purpose of ***kindly helping nature*** to burn the gas of the coal, and which, adopting the popular term, and with the view of keeping up the attractive illusion, they call smoke. These continue springing weekly into existence. Many of the more recent ones, though similar in all that could produce any good effect, yet vary in some unimportant and even mischievous adjuncts and details, but which the public are wholly incompetent to distinguish or appreciate. The mere increase in the number of patents can be no objection. Were the description, ***modus operandi***, or ascertained effect given in trustworthy intelligible terms, the community would be directly benefited, and ***number*** would be a positive good, as each would convey some new idea or modification of well-known movements or processes. It is the incongruous character and often positive deceptions set out in plausible specifications, and more plausible ***ad captandum*** descriptions, that create a new evil. Where mystery and studied concealment take the place of sound and simple statements, the community are bewildered—discrimination or choice are out of the question, and the mere rubbish so predominates as to be a positive nuisance. This might have been anticipated in the new patent law — rendering it obligatory on patentees that their several specifications should be fiated by some competent official department, from which explanations might be obtained and obscurities cleared up.

In addition to the list of inventions for smoke-consuming furnaces, inserted in the ample catalogue of the last (the seventh) exhibition of inventions by the Society of Arts, a more copious list was published in pursuance of the public meeting held at *Leeds* in 1842, Wm. Beckett, M.P., in the chair. The exhibition of models and presence of patentees was there considerable, and the meeting numerously attended. A long discussion followed. Each patentee explained the peculiar and supposed merits of his own apparatus. Nevertheless, the whole ended with the following lame and impotent conclusion, viz. :—"That in the opinion of this meeting the smoke arising from steam-engine fires and furnaces *can be consumed*, and that, too, in many cases, without injury to the boilers, and with a saving of fuel!" A committee was appointed for the purpose of inquiry, consisting of sixty highly respectable members. A subscription was entered into for defraying the expense of future investigations, and so ended a meeting, carried through with considerable spirit and promise, but utterly barren of fruit—the subject itself remaining *in statu quo.*

It was manifest that the meeting and Committee were alike incompetent to the task of extracting any useful information from the incongruous materials brought before them. Instead of a qualified jury, or selection of scientific men (*not patentees*), competent to examine the subject in its chemical and practical bearings, and test the merits of each invention, the committee consisted of mechanical engineers, manufacturers, clergymen and others, and who were expected to examine and report on a subject which had already received the attention of the highest chemical authorities of the age. The great and besetting evil which had hitherto pervaded the inquiry here again prevailed, viz.—that the *true character of the disease complained of was not either recognised or investigated.*

Of the incompetence of Parliamentary committees or bodies of men indiscriminately brought together to investigate such a subject there cannot be a more striking proof than is to be found in the report of the "General Board of Health" of the metropolis, addressed to her Majesty's Secretary of State, though but recently printed by Parliament; and which appears to have suggested the details of the recent act called Lord Palmerston's Act.

This report of the Board of Health purports to be a "Digest of Information obtained with Regard to the Operation of Inventions for the Consumption of Smoke." The mere enunciation of such a purpose and such a result is amply sufficient to stamp the whole proceedings with that character of wrong-headedness which its perusal so fully justifies. It is, with rare exceptions, a mere incongruous collection of the sayings and doings of patentees and stokers. The Board, as it were, to put their incompetency to the test, and bring it more prominently into view, sum up their *quasi* deliberations with "twelve conclusions."

These, however, are in general so incorrect and misleading as to call for an examination in detail, and which will hereafter be given. (See appendix, No. 1.)

With the view, then, of leading to some useful inference, it will here be necessary, instead of giving a list of patentees and titles, to range their claims under such heads as will convey a correct idea of their respective peculiarities. The following classification will be sufficiently comprehensive :—

Firstly,—Those which affect to "burn the smoke" by bringing it into connexion with *a body of fuel already in an incandescent state.*

Secondly,—Those which rely on the *use of hot air* as the means of effecting the combustion of the smoke or volatile portion of the coal.

Thirdly,—Those which rely on producing a uniform and continuous supply of fuel in the furnace by some *mechanical apparatus.*

Fourthly,—Those in which the supplying the *necessary quantity of air* is relied on as the main principle in effecting perfect combustion, and avoiding the formation of smoke. These will here be considered under their respective heads.

SECTION III.

OF THE CLASS OF INVENTIONS WHICH AFFECT TO BURN THE SMOKE OR GAS IN A FURNACE BY BRINGING IT INTO CONNEXION WITH A BODY OF FUEL ALREADY IN AN INCANDESCENT STATE.

Among the patented inventions which affect to burn the smoke or gas issuing from coal in this way, that of the justly-celebrated James Watt claims the first attention, not only as being first in point of time, but from the well-merited fame of the patentee.

Watt's patent was taken out in 1785; and was founded on the supposition that smoke was a mass of combustible matter, and therefore required, literally, *to be burned.* In his specification he sums up in these words :—"Lastly, my invention consists in the method of consuming smoke and increasing the heat by causing the smoke and flame of fresh fuel to pass through very hot funnels or pipes, or among, *through, or near to fuel which is intensely hot,* and which has ceased to smoke :"—and then follows that part of his instructions which his successors have so strangely neglected,—"and by mixing it with fresh air, when in these circumstances."

It is clear Watt felt the necessity for mixing the air with the gas, which he naturally called smoke. His error lay in considering the application of *extraneous heat* as essential to its combustion. His followers have neglected that part of his instructions in which he was right,—the "mixing with fresh air;" and have adopted that in which he was wrong, —the bringing the gas or smoke "*through, over, or among intensely hot fuel.*" In justice, however, to that eminent man, we must bear in mind that when his patent was taken out, nothing was known as to the quantity of air required for the process of combustion,—the part, chemically considered, which air acted in that process,—or even of what the combustible itself consisted.

The idea that a separate body of incandescent fuel was necessary to supply the heat supposed to be required for effecting combustion, has, unfortunately, been continued to our time, although any chemical work of authority would have shown that no possible degree of heat alone can effect combustion, which means, the *chemical union* of the combustible with atmospheric oxygen.

All authorities concur in showing that the bringing the gaseous products of coal into contact with other fuel, already "intensely hot," is essentially wrong. That on the other hand, if it be duly brought into *contact with the air,* apart from incandescent fuel, the process of combustion will be completed. As this principle of Watt is still adopted by many

of the most recent patentees, it will be necessary further to examine the subject in reference to the degree of heat which should be maintained in a furnace, and the object which that heat has to effect.

It is asserted by a recent writer in the Society's Journal and reiterated by many, that "the conditions requisite for combustion, meaning the fuel and the oxygen, must be brought into, and subjected to a sufficient heat to unite them." This, however, is but a repetition of the erroneous theory of Watt, and involves a manifest absurdity, since, according to it, there must always be a pre-existing continuous and separate body of incandescent fuel, to supply this "*sufficient heat.*"

Chemistry on the other hand shows that for the continued combustion either of the hydrogen or the carbon of the gas of coal, the necessary heat comes, not from any separate or extraneous source, but *literally from themselves* on their union, and in a continued succession. As well may it be said that the presence of some separate and intensely heated fuel is required for producing the flame and continuing the combustion of the gas from our ordinary burners. Common observation, on the contrary, shows, that after the application of a mere lighted taper to the issuing gas, the heat required for *continued ignition and combustion*, is *derived from* itself. Flame and subsequent combustion is demonstratively proved to be a self-generated succession, increasing, or diminishing, in the ratio of the supply of the combustible, and its contact with the due equivalent of air—and ceasing the moment when that succession is interrupted.

It seems strange, indeed, that so self-evident a proof of this continuous character of flame should have been overlooked by Watt; and that he should be possessed with the idea that to effect the combustion of the gaseous matter evolved from coal, it required to be passed through or over a body of incandescent fuel; yet still more strange is it that any one in modern times, with such clear proofs under their eyes, by the constant use of this coal gas, that such is not necessary, should nevertheless persevere in entertaining so unscientific a system.

The continuous character of flame, and its own heat-generating principle, may be illustrated by the familiar experiment of a train of gunpowder. On applying a taper to the first grain of the series, the heat evolved by its combustion performs the same office for the grain next adjoining, as the taper did for the first; and so successively to the last — thus proving the continuous character of combustion without the aid of other sources of heat. So it is with the gas issuing from the beak of the burner, or direct from the coal in the furnace. So in the combustion of even the carbon alone, apart from the gas, the continuously raising the temperature of the atoms next in succession, may be seen when we light a piece of paper. On blowing out the flame, and leaving its carbon unconsumed (and which really is, then, *the coke* of the paper), we perceive the continued process of combustion going on,—each atom, as it combines with the oxygen of the air, raising the temperature of the atom next in contact to that of incandescence, and thus enabling the latter to effect its own combustion with the appearance of a brilliant running or continuing spark. Looking, then, at the continuous character of the combustion, either of the hydrogen or carbon of the gas, *if the access of the air be also continued,* we see that the process is wholly irrespective of, and has no possible connexion with, a mass of "*intensely hot fuel,*" as supposed by Watt, and still asserted by many.

That the idea of Watt still prevails is unmistakeably shown by the recent patents, embodying the principle, and in its very terms. In a late number of the *Glasgow Practical Mechanics Journal* is given the description of a recent patent for a "smoke-consuming furnace," in which it is stated that, "the smoke or bituminous vapour of the green fire is caused to pass *through fuel that has been previously coked*:" yet nothing can be more incorrect than such statement of patentees, or more opposed to the processes of nature;—what was wanted being air, not heat, to effect combustion. While such errors and contradictions pass current on the unscientific public, how is truth to be developed, and who is to undertake the task?

Connected with this theory of Watt may be mentioned a numerous class of patents, the leading feature of which is the supplying the fuel from hoppers placed in front of the furnace. Under this arrangement the fresh coal is placed near the door, the gas from which passes over the incandescent fuel on the after part of the bars, and is then said *to be burnt*. Chemistry, however, teaches us that the passing the gas through incandescent fuel *aids* considerably in the generation, not of *incombustible carbonic acid*, but of *combustible carbonic oxide;* and that incandescent fuel is a powerful generator of this latter gas, but which, if not itself supplied with air, though it passes away *invisibly*, is nevertheless a *pro-tanto* loss of combustible matter.

Professor Graham in his *Elements of Chemistry* observes with great clearness,—"Carbonic oxide may be obtained by transmitting carbonic acid over red-hot fragments of charcoal. It is easily kindled, combines with half its volume of oxygen, forming carbonic acid, which retains the original volume of the carbonic oxide. The combustion is often witnessed in a coke or charcoal fire. The carbonic acid produced in the lower part of the fire is converted into carbonic oxide as it passes up through the red-hot embers." This is conclusive, not only as to the existence of this gas in large volumes (as may be seen in the fire-box of a locomotive engine), but of the absolute necessity of supplying a large quantity of air to effect the combustion of this gas, and at a time when, because the products are invisible, it is erroneously supposed that no further supply of air should be admitted.

Of the object then for which a body of fuel should at all times be maintained on the furnace grate in the state of incandescence, we see it can have no more reference to effecting the combustion of the gas (called the smoke), than if that gas had to be collected and burned elsewhere for illuminating or culinary purposes. Its use, then, consists in being the means, First, of effecting the continuous generation of the volatile portion of the coal from each fresh charge; and Secondly, leading to its own combustion by the air received from the ash-pit.

SECTION IV.

OF THE CLASS OF INVENTIONS WHICH AFFECT TO "BURN SMOKE" BY THE USE OF HOT AIR.

HAVING shown the error into which Watt fell in supposing that smoke could be burned by being passed "through fuel that is intensely hot," we have

next to consider the class of inventions based on the prevailing erroneous theory, that it may be effected by the use of *hot air*.

This theory is founded on the assumption that air, when heated, becomes more effective in promoting combustion than when at atmospheric temperature. Under this impression much ingenuity has been directed to the devising means by which the air may be heated before being introduced to the flame and gases in the furnace. Its advocates, however, neither refer to any authority, nor assign any reason for their belief. To say that the air has been heated, or that it has produced any given effect, is but a mere assertion. In this age of strict analysis, mere assertion, however, no matter who may be the authority, justly goes for nothing. What is stated as having been done, must be *proved;* and the proof must be within the power of all inquirers or experimenters.

It is probable that those who first thought of applying the principle of hot air to the ordinary furnaces of steam boilers (among the earliest of whom was Mr. Coad), really had faith in its supposed efficacy in generating heat. The delusion was a natural one, and was manifestly promoted by the success of the *hot-blast* system in the manufacture of iron, a less weight of coke being consumed in the reduction of a ton of iron than when cold air was employed. It being alleged that the same *weight* of air continued to be forced into the furnace, although at a *higher temperature,* this assumed fact excited the attention of some scientific men in Glasgow, who could not reconcile the idea that a given weight of air, increased in volume by its increased temperature, could be impelled through the same orifices, and by the same amount of pressure. As the quantity of heat generated could only be in the ratio of *the weight,* not *the volume* of oxygen taken into union with the combustible, consequently, a ton weight of air would generate but the same number of units of heat, whether it was at 50 degrees or 500. The history of the original misconception as to the quantity of air that actually entered the furnace, and its subsequent rectification, was fully given in the *Glasgow Chronicle* of 1829.

When hot-air blast is used to smelt iron, the air, being heated *in transitu,* and by a *separate furnace,* enters the smelting furnace at 600 deg. The *volume* is, of course, doubled. By means, however, of the enlarged tuyeres, or orifices of introduction, subsequently adopted, the *same weight* is now introduced as before its being heated. In making a ton of iron the weight of air is greater than that of all the other materials—*ore, fuel and flux.* If thrown in *cold* at the place where the lumps of metal ore are required to be kept at the greatest heat and highest temperature, and being projected against them, it would necessarily chill their surfaces, then at the melting point. This is, in a great measure, prevented by heating the air, and in this consists the chief advantage of the hot-blast.

On the effect of the hot air, Mr. Neilson, the inventor of the hot-blast system, was himself evidently mistaken. In his letter (see the *Transactions of the Civil Engineers*), describing the origin of his discovery, he observes:—"In prosecuting the experiments, circumstances became apparent to me which induced the belief, on my part, that, *heating the air introduced for supporting combustion into air furnaces, materially increased its efficacy in this respect.*" This was shown to be erroneous—the efficacy being increased not in "*supporting combustion,*" but, as already observed, by *sustaining the high temperature of the surface of the ore lumps,* and thus facilitating their fusion, but which the contact of cold air would have retarded.

We see, then, that no analogy whatever exists between the application of hot air in the furnaces of steam boilers, where the air comes into contact with the *fuel alone,* and in those for the manufacture of iron, where it acts directly on the body to be melted, namely—the ore. The hot-blast system, nevertheless, continuing in favour, the public have since been led into innumerable errors by the smoke-burning patentees, who adopted the supposed use of *hot-air* as a mere *ad captandum* ruse. Numerous patents were taken out, under which it was assumed that the air would be even *intensely heated,* but which proved to be mere attractive expedients for gaining public favour.

In 1839, the so-called *Argand furnace* brought under notice the necessity for introducing a separate and large additional supply of air to the *gases* generated in the furnace, independently of what passed to the *coke* portions of the coal through the bars—the gross quantity to be introduced being, then, far greater than had previously been contemplated, or even considered practicable (see Dr. Ure's *Dictionary of Arts,*—title, "Smoke Nuisance"). This introduction of cold air to the furnace excited much opposition on the part of furnace architects, inasmuch as it necessitated a total change in their calculations. It was then asserted by many, and in a printed letter by a Manchester engineer who then assumed to be an authority, that, "Cold air passing into the flame, drives the latter up against the boiler bottom in the manner of *a blow-pipe,* causing it to impinge with peculiar intensity up against that part of the boiler bottom immediately exposed to the direction of the blast." Again, that, "On the other hand, as soon as the fire-grate had burned bright, the cold air, striking against the same part of the boiler bottom which had just before been so unduly expanded by intense heat, a sudden contraction of the metal necessarily ensues, producing such an *alternate heating and cooling,* with accompanying *expansion and contraction* of the boiler plates as would inevitably cause their destruction." The application of a little common-sense and common observation might have prevented this display of prejudice or ignorance. A moment's inspection, indeed, of what takes place *within a furnace* at once exposes the absurdity of these comments. Besides that, so long as the water remains in contact with the boiler plates, such a thing as alternate contraction and expansion of the plate is a physical impossibility, the temperature of the plate never exceeding that of boiling water.*

That a body of air entering the furnace chamber in a soft, expanding, diverging form—as water from the rose of the watering pot, should "*drive the flame before it*" and then act as a *blow-pipe,*—in other words, should at once be *expanded* and *concentrated,*—needs no comment; but that this cold air should also *pass through the flame,* and then chill and contract the iron plates, is too absurd to require notice, except that it is necessary to direct attention to statements which had, and still have, currency and influence among the unreflecting or inexperienced. Besides, that so many patentees continue to have a direct interest in upholding the imaginary and mysterious value of hot

* See treatise, *On the Combustion of Coal,* chapter xii., "On the circulation of the water in relation to the durability of the plates."

air, by which they are sustained, and which forms their commercial capital.

Among the plans for heating the air, the passing it through hollow bars, or passages in the sides of the furnace, were patented to a great extent. No proof, however, was offered as to the temperature to which the air would be raised, or whether it was, in any sensible degree, increased by such means. Indeed, when we consider how difficult it is to heat a mass of air, and that the quantity required for the combustion of *the gas only* of a ton of coal would fill a tube of twelve inches square (the area of an ordinary furnace door), and above *thirty miles in length*, the idea of heating such an enormous volume by such insignificant means almost borders on the ridiculous.

Another of the patented attempts at heating the air, by Chaunter, Stevens, and others, even to the present day, consists in the adoption of a supplemental grate beneath the back end of the ordinary furnace bars, thus forming, as it were, a *double*, or *secondary small fire, between which two fires the air passed* (and by which it was said to be *intensely heated*), finally issuing through the aperture of the well-known split bridge of Mr. Parkes, to the gases and flame which passed over it.

The principle on which that patent of Parkes was based is chemically correct. By it the air was introduced in a thin film, through, or behind the bridge, and thus brought directly into contact with the passing flame and gases. Where the generation of gas was continuous and moderate, as was then practised under a system of large charges of many hours' duration, with slow combustion, the effect was complete. Where, however, the firing was required to be active, and the demand for steam was great, or irregular, the supply of air by the split bridge became insufficient and unavailable.

As an instance in which this simple and useful mode of introducing the air has been re-invented, and re-patented, though overlaid with contrivances by which the air was supposed to be heated, the following extracts may be given in the words of the patentee himself. In this every plausible lure is enlisted, viz., the use of "*calorific plates*"—without any explanation as to what that use effected:—the "passing the air through *two strata of fire*"—as if such were possible without its parting with much of its oxygen—the assuming "the air to be *intensely heated*"—but without any proof of the fact;—the supposed, "*entire combustion of the gaseous products* of the fuel"—equally without proof:—the obtaining the "advantages of the hot blast, without any pneumatic apparatus," but without explaining in what those advantages consisted; and lastly, the asserted—"saving of at least 20 per cent. of fuel." When also it is taken into account that these wondrous results were to be produced by "the mere scoriæ or cinders voided from the upper set of bars," this description is reduced to its *quantum meruit* of value. All this, however, is still pressed on public attention, and doubtless credited by those who are unable to detect its numerous fallacies, or see that whatever good effect might be produced was solely attributable to the introducing the air in a thin film through the split bridge; and which, when applied to small furnaces, where *the air had previously been altogether excluded*, could not fail of effecting more or less the combustion of the gases, as Mr. Parkes did, and of course, with a commensurate diminution of the formation of smoke—the whole of which however was erroneously placed to the credit of the *hot air, calorific plates, and double fires.*

As the supposed advantage of the hot-air theory continues to be urged, it will be necessary to go further into the inquiry. What then, it may be asked, is the effect of heating *on the air itself? Chemically*, there would be none whatever. *Mechanically*, however, an injuriously effective change would be produced, namely, the increasing its bulk, in the ratio of its increased temperature, doubling that bulk for every 480 degrees of heat. Now, as the bulk of the air *absolutely required* is already inconveniently large—being *ten times that of the gas*, independently of the *extra* quantity hereafter alluded to, any further enlargement can only increase the difficulty in effecting that mixing and diffusion, which is the *sine qua non* of chemical action.

As each cubic foot of gas requires absolutely the oxygen of ten cubic feet of air at a temperature of 50 deg.—the point for consideration is, whether these would be more effective in generating heat, if introduced at 50 deg., or 500 deg. This is determined by the fact already mentioned, that it is not the *volume* but the *weight* of oxygen taken up by the combustible that determines the measure of effect in combustion. On this there is no doubt.

To test the fact of enlargement of the volume of the air by increasing its temperature, introduce into a large bladder 100 cubic inches of air at 50 deg.—the weight of which would be about 31 grains. The bladder being then but half filled—suspend it before a strong fire until its temperature be raised to 500 deg.; the result will be, that the *bulk will be doubled*—the bladder will then be full, and will contain 200 cubic inches of air. Nevertheless, *its weight* will continue as before—namely, but 31 grains. If, then, these 200 cubic inches at 500 deg. contain no more oxygen than the 100 at 50 deg., it necessarily could produce no more heat, and effect no greater amount of combustion.

Now, suppose this performed on the large scale of the furnace. The quantity of gas evolved from each ton of coal being about 10,000 cubic feet, requiring 100,000 cubic feet of air, were this quantity of air *doubled in volume by being heated*, it would then be necessary to introduce 200,000 cubic feet to effect the same purpose. On this it is only necessary to observe, that such a volume of air could not possibly obtain access, unless introduced *in a mass*, as when the furnace door is opened, or by the aid of mechanical pressure, as in the reduction of iron ore.

Thus, we see how idle and even mischievous must be the result of any process for heating the air with the view, as it were, of assisting nature in its work of combustion. It is, in truth, wilfully flying in the face of nature's processes and chemical laws, and with the suicidal and absurd purposes—first, of increasing the temperature of the furnace by robbing it of its own heat; secondly, of causing the enlargement of the already almost unmanageable bulk of air which must be introduced to effect combustion; and, lastly, of endeavouring to raise the temperature of the combustible carbon which was already, and at the very moment at that of incandescence, or above 3,000 deg.

It may here be well to contrast the opposition to the introduction of the air *direct to the gases in the furnace* which for so many years prevented the adoption of so simple and natural a process, with its almost universal adoption by modern patentees. For this purpose, several of the most recent proofs of the value of the system will be hereafter mentioned.

It is true, in general it is accompanied with the attractive statement that it is "*heated.*" Until, however, some proof is given that any appreciable increase of temperature has been obtained, these statements may be placed in the category of assertions made for the sole purpose of mere mercantile attraction.

SECTION V.

OF THE CLASS OF INVENTIONS WHICH RELY FOR THE COMBUSTION OR PREVENTION OF SMOKE ON MECHANICAL APPARATUS.

THE most prominent, as well as the most successful of these, are, Brunton's revolving grate; Stanley's self-feeding apparatus; and Juckes's moving bars. That any merely *mechanical* movement could be instrumental in effecting *combustion*, which is so exclusively a *chemical* process, cannot be entertained. All that mechanism can do, is to give motion to the solid or coke portion of the fuel resting on the bars—the extent to which that motion may influence the action or introduction of the air is alone the cause and measure of its value, but which is practically so overlooked.

The object of the three plans here mentioned, and in which they are all successful, is, the supplying continuously a given quantity of coal to the furnace, and preserving a uniform depth over the entire surface. From this mechanical uniformity of supply and distribution, however, all its advantages, as regards *combustion*, are derived.

Brunton's invention was fully explained by himself before a committee of the House of Commons (See "Report on Steam Engines and Furnaces, 1819")—as follows:—"First, I put the coal upon the grate by small quantities, and at very short intervals, say two or three seconds; Secondly, I so dispose of the coal upon the grate, that the smoke evolved must pass over that part of the grate upon which the coal is *in full combustion, and is thereby consumed;* Thirdly, as the *introduction of the coal is uniform in short spaces of time, the introduction of air is also uniform, and requires no attention from the fireman.*"

Here is a correct description of the plan, mechanically considered, and its useful effect,—the latter being comprised in this, that—"the *introduction of the air is uniform.*" Now, if a stratum of coal on the bars be kept *thin, and uniformly spread over the whole surface*, the result will be a uniform admission, or passage of air through it in all parts, and concurrently with the evolution of the gas from such coal. The effect therefore will be complete,—satisfying, as it does, the law that no more gas (erroneously called smoke by Brunton), will be evolved in any one place than can come instantaneously into contact with the due quantity of air, and by which its combustion will be effected. This description and effect is equally applicable to the other two plans mentioned.

That Brunton's idea (following the erroneous theory of Watt), as to the smoke being consumed by passing over that part of the grate upon which the coal is in full combustion, was erroneous, is shown by the effect being equally complete in Stanley's apparatus, where no provision of the kind exists—the coal being there spread equally, and at once, over the entire surface of the fuel.

Juckes's apparatus is described as "an arrangement of endless chains, which, being caused to revolve upon cylinders, stretch the chains, as it were, from one end of the furnace space to the other: such chains, being formed of links a few inches long, constitute in themselves the fire-bar surface of the furnace. Over the outward end is fixed a contrivance for feeding the apparatus with *small coal,* and motion being given to the machine the fuel is *carried gradually onward.*" In this description nothing is said as to the principle on which it is based, or the cause of the advantage attributed to the bar movement and thin stratum of fuel; neither is any notice taken of its influence on the introduction of the air; yet on this exclusively its value rests. This may be stated in the words just quoted from Brunton. In one large establishment it is declared to be satisfactory as regards the prevention of smoke, and that a considerable economy has attended its use. This, however, is admitted by the proprietor to be attributable to the circumstance—not that less weight of coal was used, but that it enabled him to use a *less costly description* of coal.

Stanley's apparatus has been largely in use in the manufacturing districts. It imparts no motion to the furnace or bars, its peculiarity and action consisting in the mode by which an inferior description of coal is distributed, or, as it were, blown over the whole surface. The coal falls from a hopper in front, between two rollers, by which it is crushed fine, and dropping continuously in an uniform quantity, is flung with considerable force by revolving fans over the entire surface of the bars. Although these three plans are different in their mechanism, they are, as regards combustion, essentially the same, the useful effect being, as described by Brunton, "*the introduction of the coal being uniform, and forming a thin stratum, the admission of the air is also uniform.*" This effect corresponds with the circular series of small vertical jets of gas as now used for culinary purposes. On looking into a furnace thus supplied with coal, the appearance is that of a bed of crocus flowers — the flame rising in numerous detached vertical jets over the whole surface of the thin bed of fuel by reason of the air passing upwards through it in small streams. All these systems, however, are incompatible with the requirements of heavy charges and more active firing.

So long, then, as the manufacturer for general operations or his steam-engine requires no more heat or steam than is compatible with the system of thin firing, combustion will be complete, and no smoke will be formed. The great defect, however, of a system of mechanical appliances for furnaces consists in its *inflexibility,* and consequent inapplicability to a more irregular state of things. For, so soon as the quantity of heat or steam required becomes greater than could be produced by that uniformity of moderate supply and demand; and when a more rapid or irregular supply of steam is called for, the uniformity on which the whole depended is broken through, and the apparatus becomes inapplicable. An irregular supply of fuel necessarily produces an irregular supply of gas, with a commensurate irregular demand for air and all the liabilities of imperfect combustion and the formation of smoke. This at once accounts for the fact, that such plans, though found all-sufficient in some manufactories, are often the reverse in others.

It would be a waste of time to enumerate the many mechanical contrivances by which the smoke-burning and hot-air advocates seek to attract attention; and the more so, as the descriptions given of their

respective peculiarities are, not unfrequently, altogether erroneous, or even imaginary; having no connexion, as already remarked, with the principle on which they are said to be based. Of this there is abundant proof in the numerous patents which, though varying in detail or unnecessary adjuncts, are, however, manifestly based on the same principle: for instance, the double or split bridge of Mr. Parkes, before noticed, and the introduction of the air through its narrow orifice to the flame and gases as they pass from the furnace.

The *Venetian blind* system has also been taken as the base of several supposed patent inventions. In one, it is introduced as having the double power of both causing the air to be *heated*, and the smoke burned. In another, the same contrivance, when applied in the ash-pit, is described as keeping both the air and the furnace bars in the *coolest state.* In a third (Prideaux), the effect is described as both *heating the air* in its passage, and *regulating the supply*, but in an (erroneously) assumed "gradually diminishing manner, in harmony with the gradually diminishing requirements of the fuel, sufficient to prevent all smoke," although no such "gradually diminishing requirements of the fuel" can possibly exist—such being a mere theoretic assumption, and incapable of proof. These Venetian blind valves are inserted in *the front* of the furnace door — to be opened on each fresh charge of coal being thrown in—to close gradually, and be shut, and the air entirely excluded, at the expiration of about eight minutes; when the charge is expected to be *one-half expended;* and when, as erroneously assumed, there would be no more gas generated during the remaining one-half of the charge, and, of course, no more demand for air.

Unfortunately, the patentee has fallen chemically and practically into error, both as to the *rate* and the *degree* in which the gas is produced from the coal.* In some cases, where this apparatus has been applied, the stokers discovered these errors, and relieved themselves from the consequences by absolutely neutralising the action of the valves and keeping them *continuously open.* By this fact (and which the writer of this essay has practically verified), the valves and their self-closing action are proved to have no value, and no relation whatever to the promoting combustion or preventing the formation of smoke—that being exclusively attributable to the series of close set and permanently fixed iron laths, set in the *back* of the door box (the valves being in the *front* part), and by which the air on its admission is divided and made to enter in thin separate streams. (See Dr. Ure's *Dictionary of Arts,* article "Smoke Nuisance.")

That a furnace producing perfect combustion under one class of circumstances and accompanied by any particular mechanical apparatus, should, under other circumstances, fail in producing the same effect, though demonstrably clear, may appear difficult of explanation: the cause, however, must be sought for anywhere but in the processes of nature. A remarkable and instructive case of this kind will be hereafter given in chapter 9.

If an Argand oil lamp burn brilliantly at one time, and be defective at another, producing much red flame and smoke,—knowing that nature's processes are uniform and invariable, we rightly infer that the cause of such defect must be either in the manipulation, or the imperfection of the apparatus. It would therefore be no reproach to Davy or Argand that their lamps should be ill-constructed or mismanaged. So in the case of the furnace. It would be unsound reasoning to infer, that the mode of introducing the air to the gases in a furnace, which in one instance would be all-efficient, must be defective, because, in another furnace, an equally good result was not produced. It cannot be the *principle,* but the *mode* of carrying it into practice that would in such case be at fault. We have then only ourselves, or our mode of investigation, to blame if we are unable to discover the cause of the discrepancy. It thus becomes the special business of the engineer to seek for the cause, and not to throw that office on the mere owner of the mill or the boiler, or to expect that the skill of the stoker is to remedy the defects or malconstruction of the furnace, or the imperfect admission of the air.

If the principle on which combustion is effected in a furnace be correct, and in conformity with nature's processes and chemical laws, and proved to be so in but a *single instance,* the scientific engineer or inquirer should be able at will, and with absolute certainty, to repeat the same *perfect* process, or to discover the source of error in the *imperfect* one. Should he be unable to do so, he must suspect his own power of investigation—as any chemist would, if he failed in effecting any process laid down in the *Pharmacopœia.* Assuredly, he is not justified in throwing the onus on the unscientific millowner or his stoker. If, however, a mystified collection of merely mechanical movements, without reference to any recognised principle or to nature's laws, is to be dignified with the title of a patent smoke-burner, and as such pressed on the uninformed public, and sanctioned by public boards, or the silence of professional engineers, it will be in vain that the public search for the cause of those varying results which are daily experienced, or the mode of remedying them.

Again, when we look at the numberless circumstances by which the most perfect processes may be defeated by accident, carelessness, or design, it is the more incumbent on the engineer to be able to distinguish between the *principle* and the *practice:* and the more so, seeing that in all these mechanical systems and patented expedients the really important condition of success is often utterly neglected, namely, the arrangements for introducing the *required quantity of air,* and the proper *mode of bringing it into contact and action* with the combustible.

But there is a description of mechanical apparatus which has not yet been patented or applied, although it is the most desirable and the most wanted—namely, that which will act the part of *the stoker* under the varying circumstances of light or heavy firing, with large or small furnaces, thus making us independent of the so-called, but hitherto *undescribed skill* said to be inherent in the office of the common stoker. In the above-mentioned three plans we see that *mechanical feeders,* or stokers, are really effective under some classes of circumstances. It is yet to be explained why they may not be made applicable to all classes and sizes of furnaces.

It is in every one's mouth that experienced stokers can, not only effect the combustion of the smoke, but produce a great saving of fuel. Are we then gravely to be told, and seriously expected to believe, that by

* The rate of generation of the gas, from a charge of coal as practically ascertained, is tabulated in the *Treatise on Combustion*, chapter 5, on "Regulating the Supply of Air by Self-acting Apparatus."

some undefined qualifications on the part of the most uneducated and hard-worked class of mere labourers, they can effect all that has been sought after by the ablest engineers, in the judicious, economic, and complete combustion of the fuel which they are employed to throw into a furnace,—irrespective of its possible mal-arrangement or ill-construction,—in the absence of due provision for the admission of air in the right quantity and manner; or under the too common miscalculation of the areas for the escape of the heated products? This cannot be insisted on. It would, in fact, be giving the office of Handel, or the organ *builder*, to the mere organ bellows *blower*, whose real duties (as in the case of the stoker) should consist in *feeding their respective machines.*

In the "Digest of the Information obtained with Reference to the Operations of the Inventions for the Consuming of Smoke," the Metropolitan Board of Health state, that, "in many cases smoke has been prevented by *good stoking alone.*" In the same strain Tredgold quotes as follows, from an author he describes as having "much experienec and worthy of attention" (Alban on the High Pressure Engine) —"The best way to ensure a regular method of firing which shall be properly adapted to the requirements of the engine,—shall be most free from smoke, and shall most tend to the saving of fuel, is to employ *a good and careful stoker.* No ingenious mechanical arrangement, no scientific apparatus, can supply his place, be it ever so approved or ever so *scientific in principle or perfect in execution.* A good fireman can, however, only be retained by preventing his occupation from becoming *too easy and simple* for him, and by thus keeping his watchfulness and care in constant action and salutary exercise. The less exertion [query, bodily or mental?] such men generally have to make, and the more convenient their occupation is for them, the more *careless and inattentive* they have a tendency to become; and, at last, nothing, not even their own danger, can awake them out of their lethargy. All machines for feeding, smoke-burning, and the like, only increase the quantity of apparatus about a steam-engine in an unnecessary and prejudicial degree, and withal, augment the derangement and danger which ensue when they fall into disorder."

Here is a sad jumble of inconsistencies from which nothing can be ascertained as to the required qualities of this good and careful stoker, or how he is to be selected or instructed. After extolling his assumed inappreciable value, he is at once supposed to belong to the lowest grade of the least trustworthy and most inconsiderate class of labourers. Now, it is strange that after such a description of the value of a good stoker, this high authority of Tredgold should himself appear unable to define in what such influential duties consist. This, therefore, demands a further inquiry.

Among the difficulties with which the stoker has to contend, there is none that creates more embarrassment, and imposes more labour on him, than an insufficient draught. This, however, is not taken into account when comparing the merits and demerits of good or bad stokers. Now if the draught were always good, we should have fewer bad stokers. This is often tested by the mere change of men and vessels. A good stoker in one steam ship is often a bad one, and eternally at variance with his engineer and commander, in another. The man was the same, but the draught—the facility it afforded him was wholly different in the different vessels. His labour was comparatively light in one, but laborious and exhausting in the other. A sufficient draught economises the labour of the stoker, leaves him few cinders to be removed, and relieves him from the necessary fatigue of stirring and forcing his fires.

All writers speak of the power of *checking* the draught by the use of *dampers*, but none give the stoker the means of *increasing* it. Tredgold points to the dampers in the Cornish boiler "by which the draught may be *regulated.*" This is a misnomer. *Regulation* means *increasing*, as well as *diminishing* the amount of draught. Now, the effect of the draught is also twofold in another respect—namely, not only in aiding the *introduction* or pressure of the *entering* air, but the *eduction* of the gaseous products of the furnace. If this latter be satisfactory, we may be sure of the former. It is evident all writers assume the draught to be sufficient when they speak of the use of the damper. Yet, the insufficiency of the draught is, in the generality of cases, the main difficulty to be contended against; and to this is often attributable, as will hereafter be shown, the impossibility of introducing the great volume of air absolutely necessary for the combustion of the furnace gases. This will be seen as we proceed in the consideration of the respective merits of the *mechanical* and the *living* human stoker.

OF THE DUTIES OF THE STOKER.

AN attempt at defining the duties of this so much be-praised official has recently been made in an anonymous tract which is now circulating largely in consequence of its coming from "The Inspector of Machinery's office, Royal Arsenal." On this account it has here also an authoritative claim to attention. In this tract we find the following extraordinary estimate and definition of the duties and qualifications of the stoker, and on which a running comment will here be made for the sake of brevity, viz.:

"It is a common mistake to suppose that any man will make a good stoker,—that any man will learn to throw coals upon the fire" [and which ought to be his sole duty],—"is quite true. But there are some men who can make a pound of coal go nearly as far as two pounds in the hands of other men" [it is to be regretted that no attempt is made to show in what this power consists, or how it is to be obtained]; "who will do so with comparatively little fatigue to themselves, and have seldom to use the poker, or have the fire door open" [no doubt with good free-burning coal and good draught]; "who manage to keep up a constant supply of steam" [by force of their own intuitive genius, of course, and without reference to the size or character of the furnace or boiler]; "who have every part of the boiler perfectly clean—all the brass work bright and polished—the stoke-hole always swept and tidy—who use the white-wash brush freely whenever they see a black spot" [which duties surely require no great exercise of reflection]; "who are always mending up the fire-bridge, and other parts of the furnace" [but which they should never be allowed to tamper or touch]; "who at the same time manage to make little or or no smoke." [By what magic influence is not stated.] "Such a man is a master of his business, and is sure to be appreciated."

Why, then, it may be asked, has not the Inspector of machinery—furnaces included, explained in what this wonder-working business consists, that has such all-commanding influence over the supply of steam

—the economy of fuel, and even the prevention of smoke? Yet, if inquiry be made, it will be found that the merit of the good stoker is often contingent on well-constructed furnaces, good draught, and good coal, and *vice versa.* If, however, unfortunately, these are wanting, the stoker has then to bear the blame which ought to be laid on the shoulders of others.

But we have next the *per contra:* "On the other hand, there are some men who do not seem to be fitted for this duty" [this undefined duty],—"who have difficulty in keeping up steam" [this of course depends on the skill of the stoker and not on the size or description of boiler or furnace, or quantity of steam required]; "who forget to watch the various gauges,—who have the place always in a litter, and who seem oppressed with hard work" [possibly, *hot* work, in an atmosphere of 100°, with frequent clearing the bars from hard or running clinkers]. "Such men are frequently poking at the fire and recklessly throwing on coal" [of course without cause or necessity, and merely for amusement and recreation]; "who have the ash-pit half filled with red-hot ashes" [possibly from bad coal, crooked, half-burnt, or ill-fitting bars]. "The chimney draught seems to forsake them" [query? should not a coal which covers the bars with a hard sheet of clinker be chargeable with this crime?]; "and all for want of a little *reflection, management, and method.*"

The reply in this case should be that once given by a hard-working and intelligent stoker to his employer, who, condemning his mode of firing, observed, "If you had given it a moment's thought you would not have done so." "But, Sir," said the stoker, "I am not paid for *thinking*, but for *using the shovel.*" The stoker, in truth, might have retaliated, and said, that had *the engineer* who constructed the furnace, given it a *moment's thought*, in providing for the admission of the air, the duties of the stoker would have been confined to their proper sphere.

Now, where no special provision is made for the introduction of the air, and where it is left to chance, —to the keeping the door ajar,—or to its making its way upwards through the bars, with all the irregularities contingent on the depth of fuel and the character of the coal; in such case, the mode of charging by the stoker will have an important influence on its admission or non-admission. Under such disadvantages the duties of the stoker are not only increased but *essentially altered* in their character, and his qualifications as a *thinking*, rather than a *working*, man, are necessarily called into requisition. Yet, Brunton's description shows that "no attention need be required from the stoker,"—thus neutralising all the required good qualities of that official.

Although a distinction is here drawn between the qualifications of a supposed good and bad stoker, nevertheless, we are still left in the dark with reference to his true business, namely, *the management of the fuel;* and not to the polishing the brasses and such like trifles. The concluding words of the above extract lead us to believe that, notwithstanding the total absence of any instructions, written or verbal, the stoker is expected to exercise "*reflection*," with some peculiar "*management and method*" of his own, but which surely should be dictated by some higher power.

On this point an experience continued through the last twenty years in the practical management of numerous large and small steam vessels and land furnaces, justifies the remark, that the duty of the stoker should be confined to the mere *feeding the furnaces, under clearly-defined instructions;* and that nothing should be left to or expected from his own untaught judgment, skill, reflection, management, or method. The sooner, then, that the operations of the *living stoker* are brought to a par with the *automaton* action of that of Brunton or Juckes, the sooner will the best mode of generating heat and steam, of avoiding the formation of smoke, and of economising the fuel, be realised. Where much is required from the stoker, we may be assured there is something seriously and radically wrong, though undiscovered or unsuspected, in the construction or arrangement of the furnaces, flues, draught, or other details, as will hereafter be shown. Let these be but properly adjusted—not by the slide rule, or rule of thumb—but by calculations based upon and in harmony with nature's now well-understood demands; —let the admission of *the air* be duly provided for, and, as it were, *measured*, with as much care and certainty as we measure *the fuel;*—let as much attention be given to the one ingredient of combustion as to the other;—and the stoker will have no duty to perform that may not be learned in a single day by any able-bodied and willing man, who will follow his instructions, and make no more draught on his own reflection or peculiar ideas of management, than when polishing the brasses or whitewashing the black spots.

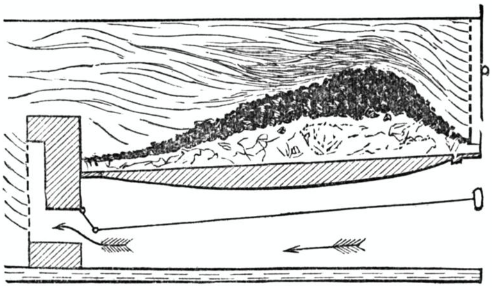
From the character of these duties, as laid down by the inspector of machinery, it would appear that his observations were more in accordance with what might be seen in the nicely-flagged and white walls of some pet and model room, with a dandy engine of 4 or 5 horse-power, rather than the rough work of the steamer, where there are six or eight large furnaces for supplying three or four large boilers, with engines of 200 or 300 horse-power—in a stoke room 15 or 20 feet below decks—an atmosphere of 80° to 100° of temperature, and where the stokers are glad to wipe their dusky brows with a handful of greasy cotton waste, and are as little able to keep themselves clean or cool as an underground collier.

It is not to be doubted, certainly, that a stoker who will doggedly persevere in exercising his own judgment, following his own crude notions, or, what is most usual, *consulting his own ease* by charging many of the furnaces together, and in such large quantities that he will have *longer intervals of rest*—it is not to be doubted that such a man may so *mismanage* the fuel as to require two pounds to do the work of one. This, however, only proves that his instructions were insufficient (if, indeed, he had any), or that his furnaces and their appendages were so imperfect as to make a constant demand on his *thought and reflection*, rather than on his *manual labour.*

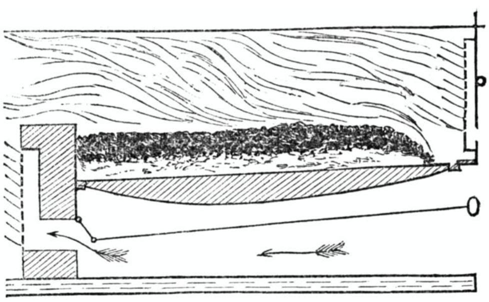
The following short code of instructions has long been advantageously adopted, accompanied by two printed placards, as in the annexed figures, descriptive of the *right and the wrong way of firing*, and which latter is so prevalent in large steamers:—

INSTRUCTIONS FOR FIREMEN.

1. The passages for the admission of air, at the door or bridge end of the furnace, should be kept open and clear of ashes.
2. Begin to charge at the end next the bridge.
3. Never allow the fire to be so low before charging that there shall not be from four to five inches of red-hot fuel equally spread on the bars.
4. At all times keep the bars equally and well covered, particularly at the sides and bridge end, where the coals burn away most rapidly.
5. Large coals should be broken into pieces not bigger than a man's fist.



WRONG WAY OF FIRING.



RIGHT WAY OF FIRING.

Now, contrast these few and intelligible instructions (which have been found all-sufficient *where the furnaces, flues, &c., are properly adjusted, and the demand for air as fully provided for as that of the coal, but not otherwise*) with the above-mentioned call for skill, reflection, management, and method on the part of the stoker, and we see the error of expecting that this hard-worked—and, too frequently, illiterate official is to remedy the miscalculations, the omissions, neglect, or want of information of the draughtsman, the boiler maker, the engineer, or the builder of the chimney-stack.

It may be asked, how it happens that this necessity for having *skilful stokers* is so generally entertained. This is susceptible of a rational explanation. An *imperfect* machine of any kind necessarily calls for greater care in *keeping it in working order* than a *perfect* one. If this were not so, watches, clocks, and other machines would not require so much attention or repairs. So it is with boilers and furnaces, flues and chimney-stacks. They are as likely to be ill-constructed, and their several parts out of harmony with each other, as any apparatus or instrument employed in the arts. Look to the real but unsuspected influence which even an ill-adjusted chimney-stack often injuriously exercises. (For a case of this kind, see that described in Section IX.) If, however, due provision be not made for bringing the two ingredients together, *the air* and *the fuel*, in the right quantity, place, and manner;—if, in fact, it be left to the stoker, of himself, practically to *discover* at what part of the furnace the fuel should be placed, and how the air may be admitted, either through the mass of the fuel on the bars, or near the door, or at the bridge end of the grate surface (for each is recommended, and on high authority);—if due areas do not exist for the *ingress* of the required great volume of air, and the *egress* of the still greater volume of heated invisible products;—under such circumstances the demand for skill, experience, and reflection on the part of the stoker will, doubtless, be great; and he who will be best able to work so imperfect a machine may well be considered, in the language of the Inspector, as "a master of his business, and sure to be appreciated."

But why should all these imperfections exist? Why should such a demand be made on the skill or reflection of this mere coalheaver? Why should he be called on to do the business, and exercise the thought which belongs to other and higher departments, or be the scape-goat to bear the blame of failures? In the absence of instructions, stokers usually adopt the plan that will give them least trouble and longer time to rest. In *steam vessels,* this is done by heaping the coal on the centre and front of the furnace and up to the doors, as shown in the figure of "the wrong way of firing," necessarily leaving the back end near the bridge with little or no coal on the bars, and where the air will, of course, enter in irregular quantities. In *land* furnaces the fuel generally appears heaped along the centre of the bar surface, as it most rapidly burns away along the sides.

In the tract just mentioned, it is said,—"There is no part of the stoker's *art*" [stoker's art!] "more difficult to acquire than the *prevention of smoke*"—thus assuming that its prevention is really within the compass of that indescribable art. With equal truth might it be said that no part of the *working engineer's art* in a steam vessel is more difficult to acquire than the preventing the waste of heat or deficiency of steam, where he has to work an engine full of defects, and a boiler possibly leaking internally and externally, or with ill-constructed furnaces and imperfect draught. In such case, the same questions arise—why should these defects exist; and why should the engineer's skill and judgment be so taxed?

Now, a *mechanical* stoker which will relieve us from this undue dependence on the "art, reflection, and management of the living *human stoker,* is a great desideratum, and assuredly will, before long, be applied—seeing that we have at length the means of surmounting the great difficulty, and have ascertained all that belongs to the introduction of the air. To some extent we see this desideratum has been supplied, as in the Cornish boilers, where the boast is that they have no stokers, at least, where nothing is required that can justify the eulogy pronounced on the good stoker making one pound of coal go as far as two, and keeping up steam," &c. "No fire-feeding or smoke-burning apparatus," says Tredgold, "are ever used in Cornwall, where they are thought unnecessary." Again, "It would be an undeserved libel on the character of the Cornish *attendants* (who *themselves* manage the fires) no *extra labouring stokers* being employed." (There is some confusion here, as the so-called *attendants* are manifestly *stokers.*) "The mode of firing adopted in Cornwall," says Tredgold, "is spreading the charge of fuel equally and thinly over the fire, and feeding the fire frequently with small quantities at a time, and with coal broken into small pieces. It is, in fact, merely a return to the method recommended by Smeaton and Watt. The former in his direction for working the York Waterworks engine, August 29, 1785, says:—'Break every coal that is bigger than a goose's egg, and the oftener you fire, and the thinner, the better. The fire should be kept an equal thickness and free from open places or holes, which are extremely prejudicial, and should be filled up as soon as they appear.'" In this respect we appear to have degenerated since 1785.

Now in these references to the Cornish boiler, we

have the precise characteristics and effect produced by Brunton, Juckes, and Stanley's mechanical feeders. When Tredgold, therefore, says, " No smoke-burning apparatus is ever used in Cornwall, where they are thought unnecessary," he should rather have said that the *most effective smoke preventive* is, in truth, there adopted,—namely, *the generating on each square foot of furnace no more gas than can be instantly supplied and combined with the due quantity of air*, and its combustion instantly effected. This is the true and only principle, whether adopted on a smaller or a larger scale—in Cornwall or Lancashire. *Nature requires no smoke-burner.* All that it requires is, not to be obstructed, and that the air be allowed the means of reaching the flue as *rapidly as the gas is generated*, before its carbon loses its high temperature, and in the way most in accordance with that diffusion which is essential to their common action.

In steam vessels, and in crowded manufacturing districts, where space is so circumscribed, and where, for that reason, the Cornish system cannot be applied, other expedients must be resorted to. Under that system, three or four large boilers are employed to produce the same quantity of steam that is done by one only, in Lancashire. Tredgold observes,—of the Cornish system :—

" 1stly. The ratio of heating surface of boiler plate in the Cornish boiler is more than *twice as great* as in the common boiler.

" 2ndly. The proportion of heating surface to the quantity of water evaporated or fuel consumed in a given time, is about *ten times* as great.

"3rdly. The rate of combustion is slower with the Cornish boiler than with the common one, in the proportion of 1 to 4."

The effects of perfect combustion we see are produced equally in the Cornish boiler, as by the mechanical appliances alluded to, under the same system of thin and frequent firing. It remains, however, to be seen whether this mechanical stoking may not be equally available where a more active firing, a greater and more irregular demand for steam, and a more rapid and larger consumption of fuel is required; and without having recourse to the costly Cornish system of *many and large boilers*. The very essence of success in the *mechanical*, as well as the *Cornish systems*, consists in reducing to a *minimum* the weight of fuel consumed in each square foot of furnace grate, in given times—such a system being so peculiarly favourable to the due *access of the air* to the *gaseous* part of the coal, and by which its combustion proceeds, *pari passu*, with that of the *solid* or coke portion from which it has proceeded. This may be thus practically demonstrated. In the action of the furnace about 150 cubic feet of air, at atmospheric temperature, are the absolute equivalents for the combustion of each pound of coal,—$\frac{1}{3}$ or 50 cubic feet of which are taken up by the *gas;* and $\frac{2}{3}$, or 100 cubic feet, by the *coke*.

Now, if the body of fuel on the bars be so thinly spread that the 50 shall continuously have access to the *gas*, and enter into combustion in *the same time* that the 100 are taken up by the *coke*,—the entire calorific effect of both will be obtained. The moment, however, that we *increase the thickness* of the body of coal on the bars (whether by the human or the mechanical stoker) the whole case is altered: a less than the due portion of the 150 cubic feet of air will then pass, in given times, through the fuel to the gas, while a greater proportion of it will be taken up by the coke. Thus, the latter will be more rapidly urged and consumed than is consistent with that of the former. If the above proportions of air be not thus relatively appropriated, the gas of the coal cannot be supplied with air as fast as it is generated, and hence its imperfect combustion and its conversion into smoke, and the necessity for other expedients.

In steam vessels, and in the furnaces of land boilers in Lancashire, where much steam is required, instead of confining the demand for steam to the quantity that would be produced from each square foot of the furnace under the Cornish system, or of those mechanically fed, recourse is had to a *more active* state of the furnace, a *thicker bed* of fuel, and a more *rapid generation of heat* and steam. In Cornwall, under such circumstances, recourse would be had to *increasing the size and number* of boilers,—still, however, wisely retaining the *leading principle* of the system, viz., *thin and frequent firing*. Thus the Cornish system depends, not on adapting the mode of firing and stoking to the demand for steam, but *the reverse;*—the adapting the boiler, by means of its increased dimensions, to that system of stoking which they find has such advantages, and which we see is also the peculiar feature of the *mechanically-fed* furnaces.

In a word, the Cornish *system* (not the Cornish *boiler*) effects the greatest economy of *fuel* at the expense of *time*, *space*, and *first cost* of boilers. The *Lancashire system*, on the other hand, economises all these latter at the expense of the *fuel*, which, in the north, is comparatively cheap. There is, then, no grounds for boasting on the part of the Cornish engineers, for effecting economy of fuel, seeing that it is accompanied by what would be impracticable, or ruinous evils elsewhere, as in close manufacturing towns.

As to the peculiar description of boiler used in Cornwall, it is a mistake to attribute any special merit to it. Any other description of boiler would be equally effective, if managed on the Cornish system of *thin and frequent firing*, and accompanied by the extraordinary care taken in husbanding the heat and preserving the steam generated. The important question then remains to be tested—whether *mechanical stoking* may not be made available in all cases.

SECTION VI.

OF EFFECTING COMBUSTION BY ATTENTION TO THE DUE ADMISSION OF THE AIR TO THE FURNACES.

HAVING examined the inventions founded,—1st. on Watt's erroneous theory of passing the volatile products of coal " through a body of incandescent fuel" —2ndly, of those who advocate the use of *hot air*,— and 3rdly, those who rely on moving *mechanical* apparatus; it now remains to be considered how Nature's processes may be best promoted by mere attention to the supply of atmospheric air. This is unquestionably the most important division of the subject, although least examined by professional engineers.

In considering the question of combustion in reference to its chemical relations, the safest course is that adopted by Sir H. Davy when engaged on a similar inquiry,—namely, by an analytical examination of the several bodies to be dealt with. On this we have now no difficulties. Chemistry has been so popularised that we are no longer in the

position of those who, some fifty years back, were ignorant of the great elementary truths which now characterise the science. On this head, Dr. Ure, one of the oldest and ablest labourers in the vineyard of science, observes,—"It was the rival logic of Sir H. Davy, aided by his unrivalled felicity of investigation, that first recalled chemistry from the labyrinth of fancy, to the more arduous career of reason. His researches on flame and combustion would alone place him in the first rank of scientific genius." To avoid being again led into the regions of fancy it is important that we steer clear of that empyricism which seems to run riot in our own time,—repudiating those theories which take their rise in mere commercial speculations.

To show that this danger is not an imaginary one, many proofs might be here adduced. Indeed we have only to look at our periodicals, and even to the pages of the Society's Journal, for unmistakeable evidence of the fact. In the paper already referred to and read before the Society, the author observes as follows:—"To save confusion I here explain what I mean by *being combustible.*" It would have been more satisfactory, and certainly less pretentious, had he examined, and given the meaning attached to the term by men of less questionable authority. But he thus proceeds: "By that term I understand the property of being *decomposable*—the *decomposition* being accompanied by heat and light; and in this sense *smoke is combustible.*"

Seeing how the public and even the Legislature have been led astray by such crudities in pursuit of the chimera of "*burning the smoke,*" in contempt of high chemical authority and of Nature's laws, it may well here be asked—"Who is this that darkeneth counsel by words without knowledge?"

It is only necessary to say, that no cross-reading could have brought together greater errors than are here promulgated, and with the *ipse dixit* air of professional authority. As a refutation of this new dogma of combustibility it would alone be sufficient to say that carbon is a combustible—yet carbon is absolutely *undecomposable.*

It is manifest that none of our chemical professors will condescend to refute such assertions, and thus, even the pages of the Society's Journal are made the channel for circulating and perpetuating such fallacies. As well might we expect our own Faraday to enter the arena with every tyro who would undertake to give him new views of electricity. As the present essay, however, is intended, not for the instruction of a class of scientific men who could not be led astray by such absurdities, but to be practically useful to the unscientific part of the community, it becomes necessary that such mistakes be pointed out, and the public cautioned against the risk of contagious errors. The following will be sufficient for this purpose.

In a work of authority—*Chemistry*, by Gmelin (printed by the Cavendish Society), it is thus stated, and in direct contradiction to the above theory: "The *combination* of oxygen with other bodies attended with light and heat is called burning, or *combustion.* In this process the oxygen is the supporter of combustion." Here we have *combination*, not *decomposition*, shown to be the principle of combustion.

Sir Robert Kane, in his *Elements of Chemistry*, observes, "In all cases where bright light is produced in combustion, one of the bodies engaged must be solid, and the light is really derived from its being ignited." Here again it is shown that combustion with light means not *decomposition*, but *the union of two bodies*, one of which must be a solid; and this is peculiarly in point, the light being caused by the *ignited carbon* (the solid), raised to the highest temperature of luminosity. Dr. Ure also speaks of "the disengagement of light and heat which accompanies *combination*," not *decomposition.*

All that can be necessary for practical purposes, then, is so distinctly laid down, even in the few works here referred to, that, to go astray would almost seem impossible. If, however, overlooking such all-sufficient public instructors, we suffer ourselves to be led into the wide field of conjecture, and expect to learn from commercial patentee speculators some principle which has hitherto escaped the researches of chemists and philosophers, we may go back to the theories of the last century when Priestly and Stahl, with their phlogostic theory, were leading scientific men astray. All that moderns require is within reach,—the work of our own time, and effected within the recollection of living men. The writer of these pages himself, when a student, heard, in the courses of William Higgins, chemical professor to the Dublin Society, the first enunciation of the atomic theory,—the foundation of that system which, in our day, has made chemistry an exact and positive science. He remembers the series of developments which subsequently marked the career of the illustrious Dalton and the no less illustrious Davy, who first laid open the processes of Nature in all that belongs to flame and combustion.

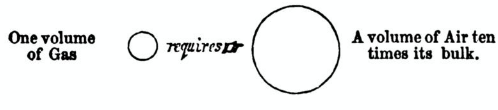
From the labours of these philosophers, we learn, that the primary and absolute condition of chemical union is, that bodies *combine in relative quantities*, called *equivalents*,—as to number, weight, and volume. Now, here is a law of nature which peculiarly demands the attention of engineers, seeing that on this depends the whole theory and practice of combustion in furnaces. What, then, can be said of those patentees, who in laying down rules for the construction of furnaces, rely on mere "*mechanical apparatus and dimensions*," in neglect of all that belongs to *one* of the two bodies to be introduced, and by which alone combustion is to be effected,—namely, *the air?*

Professor Brande says, "Combustion cannot be considered as dependent on any peculiar principle or form of matter, but as a general result of intense chemical action." By the researches of Despretz, the heat evolved in all cases of combustion, depends, not on the *combustible*, but upon the *quantity of oxygen combined.* Thus a pound of oxygen in combining respectively with hydrogen, charcoal, alcohol, or ether, evolved in each case very nearly the same quantity of heat,—each raising 29lbs. of water from 32° to 212°. Here again we find combustion to be the effect of *combination*, not *decomposition.*

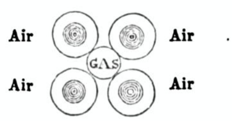
It is here necessary to remove a misapprehension as to what is meant by the term *mixture, or contact*, in connexion with the term *atomic.* If two *solid* bodies touch each other, that is properly called contact. In treating, however, of the action of *fluid or gaseous* bodies, the term means *atomic*, not *collective* contact. The bodies to be brought into such contact are, not two masses of gas and air in their *collective* capacities, but the *individual atoms*, or particles, of which such masses are respectively composed; for these are the bodies in their separate and *individual relations* between the equivalents of which the union is to be effected. Thus, to effect the combustion of a single atom of the gas, it is absolutely necessary

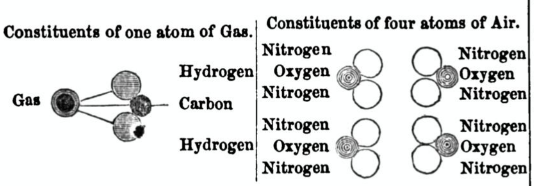
that it obtain, as it were, *personal* contact with four atoms of air; and for this reason, that the oxygen which these four contain are the precise and indispensable equivalents of the hydrogen and carbon which formed its constituents; and so of every atom of the mass. The annexed diagram will sufficiently point out not only the constituents and equivalents of the gas and atmospheric air, but the respective volumes of each and their several unions during the process of combustion.

SYNOPSIS OF THE COMBUSTION OF COAL GAS IN ATMOSPHERIC AIR.

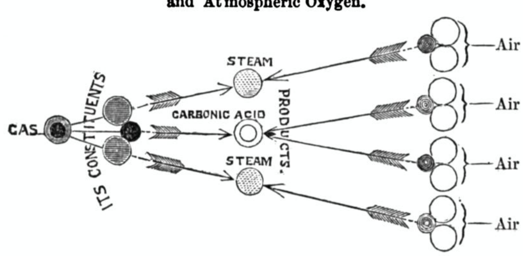


Mechanical *mixture* preparatory to Chemical *union.*





Chemical union or combustion of the respective equivalents of Gas and Atmospheric Oxygen.



In the view of unscientific men, this consideration of bodies in their atomic state appears an overstrained detail, even bordering on trifling. Even Dalton was, at one time, subject to ridicule for such advocacy. It is asked, what is an atom? how can we distinguish it or determine its weight or volume? and where can be the use, for practical purposes, of this microscopic view of nature? This, however, is not the place to admit of such a controversy.

When Professor Faraday was consulted by the Athenæum Club on the injury arising from the use of gas in their library, they were not deterred from "rushing into the bosom of high chemical authority." On the contrary, it was to that very authority they applied, and on a subject closely in connexion with the one here under consideration. Neither was the Professor himself deterred from a chemical analysis of combustion when suggesting a remedy against this mere domestic inconvenience. In his report to the Athenæum Club he describes, in detail, the constituents of the gas and the air, and the products of their union and combustion:—finally pointing to the remedy at which he arrived by this analytical examination.

In what is called the *Argand furnace* the effect is produced exclusively by aiding the immediate mixing operation among these chemical equivalents,—the air, for that purpose, being introduced to the gas in a *divided state in numerous jets or films,* as water is more effectually mixed with the air by passing it through the perforated rose of the watering pot or by the artificial jet d'eau. On the value of this, Sir Robert Kane, in a letter to the author of this essay, observes:—

"The introduction of the air to supply the oxygen necessary for the combustion of the volatile products of the coal,—the diffusion of this air, secured by its issuing from a *great number of small jets,* and the consequent full combustion of the gaseous fuel, are all *elements of real economy and success* in practice. The value of this, although, perhaps, obscurely felt by others from the imperfection of the older methods, has been certainly first placed in its important and just aspect by your illustrations."

This authority needs no confirmation, and sets the question at rest as to the value and necessity of introducing the air in a *divided state.*

The supplying the air in such quantities, and in such a manner as will effect the combustion of *both the hydrogen and the carbon,* is not sufficiently attended to in practice; for if the air be slowly, or too scantily, or improperly supplied, the *entire of the oxygen* will be taken up by the *hydrogen, and none whatever will remain for the carbon,* thus producing the light of flame without the combustion of the carbon (the solid) which caused its luminosity. It is this which practically renders it necessary that the supply of air should always be *in excess of the absolute theoretic demand* for combustion.

The opinion of that able chemist, the late Professor Daniell, of King's College, is much to the point. Having been consulted expressly on this subject, he gave his deliberate opinion in the following words:—

"With regard to the different forms of hydrocarbon it is well known that the *whole of the carbon* is never combined with oxygen in the process of detonation, or silent combustion, *unless a large excess of oxygen be present.* For the complete combustion of olefiant gas, it is necessary to mix the gas with *five times* its volume of oxygen, though *three* only are consumed. If less be used, part of the carbon escapes combination and is deposited as a *black powder.* Even sub-carburetted hydrogen (our common coal gas) it is necessary to mix with more *than twice its bulk of oxygen, or the same precipitation will occur.* It is clear, therefore, that the whole of *the hydrogen* of any of the compounds of carbon may be combined with oxygen, while a part of *their carbon* may escape combustion, and that, even, when enough of oxygen is present for its saturation."

Here it is clearly shown that *an excess of air should always be supplied, to give the excess of oxygen required beyond what the combustion of the gas demands.* This Professor Daniell has shown is the case of deliberate laboratory practice, and to apply it to the case of a furnace, he adds:—

"That which takes place when the mixture is *designedly made in the most perfect manner,* must undoubtedly arise in the common process of combustion (in a furnace) where the mixture is *fortuitous, and much less intimate.*"

This at once disposes of the objection to the supply of air being *in excess* of the theoretic demands of the gas. The professor sums up in this emphatic manner:—

"Any method of insuring the complete combustion of fuel, consisting partly of the volatile hydrocarbons, must be founded upon the principle of producing an *intimate mixture* with them of atmospheric air *in excess, in that part of the furnace to which they naturally rise.* In the common construction of furnaces this is scarcely possible, as the oxygen of air which passes *through the fire-bars is mostly expended on the solid part of the ignited fuel* with which it first comes into contact."

These concluding words are peculiarly important as pointing to the error which prevails, even to this

day, in supposing that the entire supply of air may most judiciously be introduced *through the bars* and from the ash-pit.

From this clear and unexceptionable evidence, we see the utter fallacy of supposing that a sufficiency of air for the perfect combustion of the gas in a furnace could be thus introduced.

The prevailing inattention of engineers to those details which involve the quantity, place, and mode of admission of the air may be traced in a great measure to overlooking the fact, that in the use of coal there are two distinct classes of combustibles, to be dealt with,—namely, the *gaseous* constituent, and the remaining *fixed carbon or coke;* each requiring its own separate supply of air, not only at *different times*, that is, successively, but in *different parts* of the furnace. Further, that as the gas itself contains two separate elements—hydrogen and carbon, these also require to be consecutively supplied with their respective equivalents of air. These constituents may be thus shown.

Each pound weight of good coal will give out 5 cubic feet of *gas*, and require for its special use 50 to 60 cubic feet of air, according to the quality of the gas; while the remaining *coke*, being about 50 to 60 per cent. of the gross weight of the coal, will require an addition of about 100 to 120 cubic feet. The products from each hundred-weight, then, in round numbers, will be as follows:—

Hydrogen	5 lbs.
Carbon in combination with the hydrogen, and forming the gas	20 lbs.
Carbon remaining as coke	60 lbs.
Nitrogen, sulphur, oxygen, and ashes	15 lbs.
	100 lbs.[1]

We here distinguish the *three* bodies into which the coal is resolved, and each requiring its own special equivalent of air, viz.—The coke, the hydrogen, and the carbon of the gas. Now, the whole question of perfect or imperfect combustion,—the utilisation of all the elements of the coal, and obtaining their relative and entire calorific effect, will be determined exclusively, and absolutely, by the facilities afforded these three bodies in obtaining their respective contact and quotas of the air supplied.

It will not be enough, therefore, for engineers to look to the naked fact, that each pound of coal will require 150 cubic feet of air, and to expect that all the contingencies of combustion will be satisfied, *if they provide that quantity*. So far from that being the case, it is exclusively on the *special application* of these 150 cubic feet to these *three separate portions* of each pound of coal, as above described, that success will depend. For, if the air be taken up by the incandescent *coke* (and to which it first finds access) more rapidly, or in greater quantities, than the *gaseous* matter can simultaneously be supplied with *its own due quantity*, the entire operation in the furnace will be deranged. In a word, the gas should have its own equivalent of air, and enter into combustion as rapidly as it is generated, and in due relation to the combustion of the coke in *equal times*.

From these facts we obtain the necessary data which are to determine the areas of the several parts of the furnace: first, for the admission of the air to the incandescent fuel on the bars; secondly, for the *ingress* of the air to the two constituents of the evolved gas; and, thirdly, for the *exit*, or escape, of the volatile products of *both the coke and the gas* to the chimney shaft, and their due current through it. These details will be commented on hereafter.

Of the value of the principle of introducing the air in a *divided state*, no stronger practical illustration need be given than its now almost universal adoption by modern patentees. Among these may be mentioned those particularly noticed by the periodicals:—Woodcock, Prideaux, O'Regan, Parker, Robertson, Hill, Bayless, Gardner, and many others. It is true the principle of introducing the air, as above described, and confirmed by so many chemical authorities, is not commented on, or even acknowledged, by such patentees; in fact, for their *personal* objects it is kept as much out of sight as possible. Nevertheless, their several specifications attest the fact that it is thus silently, though surreptitiously, making its way into practice.

In the examination of these patents we have a further proof of the impossibility of obtaining any correct or reliable information as to the working of their several so-called inventions, seeing that each relies and expatiates on something specially introduced to support the character of originality although they all depend for success on the one principle of introducing large supplies of air in a *divided state*, so as the more rapidly to affect the mixing and diffusion with the gas in the furnace.

On the expiration of the patent of 1839, when this mode of introducing the air became public property, many patentees, who before had opposed it, seeing its importance made it the basis of new patents, while many new speculators entered the field of competition. A brief examination of some of the recent patents will furnish sufficient evidence of the fact, and also of the *improved practice* of the present time.

The first change worthy of notice is, that the old and unsound doctrine of introducing the air to the furnace exclusively *through the bars* and the fuel on them, is now passed by,—that of introducing it direct to the gases, at length taking its place, after a continued and vigorous opposition of fifteen years. The claim to the mode of admitting the air, as described by the specification of the patent of 1839, and which should be known that the public may see the extent of the imitation, is as follows, viz.:—"The use, construction, and application of perforated air distributors, by which the air is more immediately and intimately blended with the combustible gases in the furnace." It will now be seen how fully this mode is appreciated, and how closely it is adhered to by the *re-invention class* of patentees.

In Woodcock's patent, the gas and the air are brought into contact by "a plate *with numerous perforations*, through which the air is admitted." Again, the patentee observes, "I prefer to administer it [the air] in thin *films, or through very small orifices*." How far his inverted, or hanging bridge, and other adjuncts may mar the operation and affect the draught, must be determined by experience. They are, however, altogether unnecessary.

O'Regan's patent is an undisguised and identical, though unacknowledged, imitation of the Argand furnace of 1839. As usual, however, several unnecessary appendages are introduced to disguise the directness of the imitation, and give the patentee something to talk about.

By Prideaux's patent, already mentioned (see his *Elementary Treatise*), the air passes through a series of perforations in the door plate. Subsequently, a

[1] Mr. Sewell, in his elementary treatise, gives the above as the mean average of 28 varieties of Lancashire coal. Mr. Murray's estimate corresponds in the main features, but gives the hydrogen and coke a little in excess of the weight here stated.

number of thin, close-set, and fixed vertical iron laths were adopted. The effect, however, is equally good. " By this arrangement," he observes, " among other important results, is secured *its subdivision into minute jets*."

In Hill's patent for " Preventing or Consuming Smoke," the means applied are, " the employment of a *perforated wall or grating*, through which the air passes."

In Parker's patent, the air is introduced directly to the gases above the fuel, by means of a " perforated plate," similar to that shown in the *Treatise on Combustion*, Fig. 40, page 90, where it is given merely as an experiment, but which, in practice, must prove inefficient from the liabilities of the plates to be destroyed.

Robertson, in his patent, pays considerable attention to supplying the air to the furnace chamber through narrow apertures in the sides. He also observes that, " the consumption of the smoke (meaning the gas) is further *assisted* by the addition of a *perforated burner near the inner end*."

Bayless, in his description of his patent, is peculiarly precise. " I propose," he observes, " to compensate for this want of time by dividing the gases into a number of small streams, and forcing them into mechanical mixture with the air. " This operation he effects by " a series of admixtures having *spaces between them for the admission of the air to commingle with the gases*." Again, " *perforated plates of metal* or slabs of fire-clay might be used, placed horiontally or vertically, as is thought best."

In Thompson's patent for " The Prevention of Smoke," the so-called invention consists of a flue which he connects with a hollow bridge; this bridge being *perforated in front and upon the top so that the two currents* of heated [cold] air pass into the bridge, *issue from the perforations*, and combine with the combustible gases given off by the fuel, and insure ther combustion.

Gardner's patent involves two contrivances, one is, the use of a *deflecting plate*; the other, the admission of the air through a *series of small orifices*. The former is wholly unnecessary, and may affect the draught, unless it be very powerful. The public, however, are led to believe that the good effect is solely attributable to the deflecting plate. This is but a subterfuge, perhaps a harmless or even justifiable one, on the part of patentees who are to live by attracting public attention, and by the exhibition of something new, or even complicated, to justify a claim to originality. It may here be observed that these patentees have introduced into their several specifications the perforated plates as air distributors as forming part of their patents. This they cannot legally claim, inasmuch as these distributors have been the subject of a previous patent, and have long continued to be extensively in use.

Now, however we may condemn any deceptive means in gaining public favour, though in the struggle of competition, we must admit the value and importance of thus introducing a principle so effective and so in harmony with Nature's laws and processes, and from which we may justly anticipate a release from the too long-established nuisance of a smoky atmosphere.

It is unnecessary further to enumerate the patents in which the principle of introducing the air direct to the gases in the furnace by jets, films, or otherwise divided streams, forms the basis of these respective so-called inventions: it is sufficient to know that the principle is daily gaining ground, and will shortly supersede the necessity for legislative interference. Thus this class of patentees, imitators though they be, are, nevertheless, working unquestionable benefit to the public, by adopting the right mode of introducing the air, and thus effecting combustion, without the production of smoke. For the present, however, and until the subject is more generally understood, and the principle adopted, *not by patentees*, but by the makers and designers of boilers, the improved practice must be effected at the expense of those who are compelled to have recourse to such agency, to avoid the penalties harshly and even unjustly imposed under the provisions of the existing law.

It may here be appropriately observed, that while these patent imitators are seeking public favour and private gain, under a false claim to invention and originality, they appear to have lost sight of the common honesty involved in the maxim, *Palmam qui meruit ferat*.

SECTION VII.

OF THE NATURE AND PROPERTIES OF SMOKE.

THE following observations on the nature and properties of smoke which do not fall within the scope of the preceding divisions of the subject, as suggested by the society, are yet important in a practical point of view. So much, indeed, has been said on the " burning of smoke," and even under Parliamentary authority, that it becomes necessary, more analytically, to examine and expose the error of considering the black cloud called smoke, to be a combustible, and merely because it contains a portion of carbon. According to the views of scientific men, the term smoke is applied to the *volatile produce* of the furnace *after* the process of flame or combustion has taken place, in contradistinction to that which issues *direct from the coal*, and which is called gas or gaseous vapours. These we have already seen, on high authority, are all combustible " from the beginning,"—on their issue from the coal. The colour alone, indeed, should have enabled us to mark this distinction; for if it be the produce of *flame*, on combustion being imperfectly effected, it will exhibit the unmistakeable *black colour or tint*, showing that *visible carbon is there*, in its deposited or separated state. Whereas, if it be merely *unconsumed gaseous* matter, it will retain its *brown, blue, or greenish hue* as we see it issuing from the coals on an open fire, or in the retorts of the gas-works.

By analysis we ascertain the constituents and characteristics of all bodies, volatile as well as solid. By the result of these analyses the chemical nomenclature of the present day has obtained so distinct and explicit a character, and a certainty amounting to mathematical precision, that it becomes a complete index to the book of nature,—as regards inorganic matter. Its neglect or repudiation, then, puts a man out of the pale of scientific inquiry. When, for instance, the writer in the Society's Journal gravely stated (and as many others do to the present day), that " smoke can be consumed, and by that is meant the *gas, vapours, smoke, or whatever else it may be called*," we have only to repeat that such a vague, *ad libitum* use of terms is wholly inadmissible; and that before the writer can have any claim on our attention he should be able to define what he himself means, and *chemically*, what it is which he asserts can be consumed.

Again, when he says that "he has seen smoke consumed a thousand times, and that it is mere trifling to assert the contrary, and rush into the bosom of high chemical authority for proof," it would be a waste of time to discuss such a subject with a disputant so ill prepared, and who seems so incapable of appreciating the necessity for using correct terms, or giving things their right names. Assuredly, "high chemical authority" will not enter the lists with such an opponent. Nevertheless, the public require to be set right.

Sir H. Davy laboured to distinguish the properties of bodies capable of entering into combustion. He even gave new and distinguishing appellatives to many, as when he gave to the oxymuriatic acid of the French chemists the name *chlorine*, from its greenish-yellow colour. In truth, nothing can be more important than an accurate nomenclature, to prevent the possibility of one body being taken for another. The smoke-burning community, however, wise in *their* generation, evade this precision, and thus keep up the mystery of "Smoke-burning."

In the present case, and for the purpose of ascertaining how the formation of smoke may be avoided, we have to examine the products of the union of both the gaseous and solid portions of the coal with the air. These products are, *water* (in the form of steam), *carbonic acid*, and *nitrogen*. Now, these are invisible and incombustible. Professor Brande, commenting on the system of introducing air in divided streams, observes:—"When that system is perfectly applied, *the smoke can consist of very little else than carbonic acid, nitrogen, and steam,—all incombustible*, and all incapable of supporting combustion."

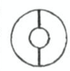
Whence, then, it may be asked, does the visible black of the cloud proceed? Solely, as will be proved, from the unconsumed portion of black carbon, insignificant though it may be in weight or volume.

This *carbon* of the gas, being the sole black-colouring element of smoke, it is here necessary to examine the several phases and conditions of its existence and progress, *before*, *during*, and *after*, it has been in the state of flame. Flame is not the combustion of the gas. Flame itself has to undergo a further process of combustion, being but a mass of carbon atoms, *still unconsumed*, though at the temperature of incandescence and high luminosity. Flame is then but one of the stages of the process of combustion. Its existence marks the moment, as regards each atom, of its separation from, and the combustion of its accompanying hydrogen, by which so intense a heat is produced as instantaneously to raise the solid carbon atom, then in contact, to that high temperature: thus preparing it the more rapidly to combine with oxygen, *so soon as it shall have obtained contact with the air, but not a moment sooner:* and wholly irrespective of any degree of heat or heated matter to which it may be exposed.

Here we again see the error of those who assert that this carbon should be brought into contact with other heated bodies (according to the theory of Watt), whether red-hot fuel, calorific plates, or hot air. Instead, however, of administering the air while the carbon is at this high temperature of 3,000° (as we see in our gas burners), our custom is first to allow it, or even *force it* to cool down, by its contact with metallic tubes, to the state of soot, and then to seek, by some mechanical apparatus, to restore it to the necessary temperature from which it had been so gratuitously reduced.

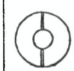
But, it may be asked, why allow it to lose its already acquired high temperature? Why create a necessity for the sake of overcoming it? It seems an act of mere stupidity to waste the high temperature the carbon had thus naturally acquired, by allowing the opportunity to pass before we administer the only thing needful—namely, *the air*.

We have seen how the carbon of the gas, in the absence of air and its oxygen, returns to its normal state of black solid atoms in the form of soot. It will here, then, be useful to mark and illustrate the several well-defined and well-understood stages through which this carbon passes from its invisible state, as a constituent of the gas, to its *visible* state in smoke. In the following diagrams representing its four stages, the carbon is placed in the centre of each figure.



First stage.—*Invisible* and *intangible*—the carbon being then in chemical union, and surrounded by the two atoms of hydrogen, forming carburetted hydrogen gas.

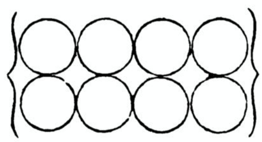
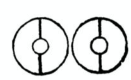
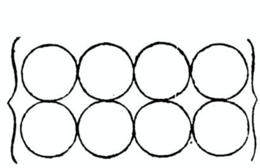
Second stage.—*Visible*, *tangible*, and raised by the heat produced on the combustion of its accompanying hydrogen to the temperature of incandescence, which, by their number, give the white luminous character to flame.



Third Stage.—*Invisible* and *intangible*, after its combustion—having then entered into union with two atoms of oxygen, and forming invisible carbonic acid (the oxygen being here represented as surrounding it).

Fourth Stage.—*Visible* and *tangible*, in the state of lamp-black, or soot, having escaped combustion by not having had access to the air, before it was cooled below the temperature required for chemical action.

Of the comparatively insignificant value of this carbon as one of the elements of the cloud of smoke, the annexed diagram will convey a sufficiently correct idea as to the relative number, weight, and bulk of each.

Number of Atoms.	Weight of Each.	Gross Weight.		
8	14	112		8 atoms of invisible nitrogen from the 4 of air that supplied the oxygen both to the hydrogen and carbon of the gas.
2	9	18		2 atoms of invisible steam from the combustion of the hydrogen of the gas.
1	6	6		1 atom of visible carbon unconsumed, and becoming the colouring matter of smoke.
2	22	44		2 atoms of invisible carbonic acid from the carbon of solid coke on the bars of a furnace.
8	14	112		8 atoms of invisible nitrogen from the 4 of air that supplied the oxygen for the combustion of the coke of the coal.
21	66	292		21 atoms.

Thus we see that out of the 21 atoms which are the constituents of any given weight or volume of smoke, the only combustible one,—the carbon weighs but 6,—the *incombustible and invisible* portion weighing 286. As to volume, we see, as above, the comparatively insignificant space it occupies, although it possesses the power of giving the black tint to the cloudy mass. These volumes are here supposed to be at atmospheric temperature. When, however, we consider that, with the exception of the *carbon*, which alone (being *a solid*) retains its original diminutive bulk, while all the others, being *gaseous*, will be enlarged to *double*, possibly to *treble* their previous bulk, in proportion to their increased temperature,—we are amazed, not only at the comparative insignificance of the carbon, but at our own credulity in believing that this merely blackened cloud could be made available as *a fuel*, and a source of heat.

Generally speaking, this black cloud is supposed to be an aggregate or *mass of carbon*, in the form of a sooty powder. This is manifestly an error, since that would assume that the three other products—nitrogen, carbonic acid, and steam—in their great volumes had been neutralised, or lost, or otherwise disposed of. As, however, that is impossible, smoke must be taken as it is,—namely, a *compound cloud of all these three* gaseous bodies, together with the portion, more or less, of the solid, uncombined, visible free carbon, then in the *fourth stage*. Here, then, is a definition of smoke, which is susceptible of the most rigorous proof.

We see the black cloud from a chimney extending for miles along the horizon, and hence conclude that the quantity of carbon must be considerable to produce such an effect. Nothing but strict chemical inquiry could have enabled us to correct this error. By it we ascertain that this black cloud is *tinted, literally but tinted*, by the atoms of carbon, and which, though issuing in countless myriads, are comparatively insignificant in weight or volume, or in commercial value as a combustible. In truth, the eye is deceived as to the mass by the extraordinary colouring effect produced by the minuteness, but great number of its atoms of carbon.

And now as to the relative *quantities* of the several constituents of smoke: 1st. Of the *invisible nitrogen*. As atmospheric air contains but 20 per cent. of oxygen, the remaining 80 per cent. being the *nitrogen* passes away, invisible and uncombined. If, then, a ton of coal requires, absolutely, for its combustion the oxygen of 300,000 cubic feet of air, the 80 per cent., or 240,000 cubic feet of invisible and incombustible nitrogen, forms the first ingredient of this black cloud. 2nd. Of the *invisible carbonic acid*. This portion of the cloud may be estimated as equal in volume to the 20 per cent. of oxygen which had effected the combustion of the carbon *both of the gas and the coke* of the coal. 3rd. Of the *invisible steam* formed by the combustion of the hydrogen of the gas. In this will be found the great source of the prevailing misapprehension; yet no facts in chemistry are more accurately defined than those which belong to the formation, weight, and volume of the constituents of steam.

The following extract from a paper read before the Institution of Civil Engineers, being from the report, already mentioned, by Professor Faraday to the Athenæum Club, is much to the point of this inquiry—particulary as regards the great volume of water resulting from the combustion of the coal gas:—

"All substances used for the purposes of illumination may be represented by oil and coal gas. Both contain carbon and hydrogen, and it is by the combustion of these elements with the oxygen of the air that light is evolved. The *carbon* produces *carbonic acid*, which is deleterious in its nature and oppressive in its action in closed apartments. The *hydrogen* produces *water*. A pound of oil contains about 0·12 of a pound of hydrogen, 0·78 of carbon, and 0·1 of oxygen. When burnt, it produces 1·07 of water, and 2·86 of carbonic acid; and the oxygen it takes from the atmosphere is equal to that contained in 13·27 cubic feet of air. A pound of London gas contains on an average 0·3 of hydrogen, and 0·7 of carbon. It produces, when burnt, 2·06 of water, 2·56 of carbonic acid gas, consumes 4·26 cubic feet of oxygen equal to the quantity contained in 19·3 cubical feet of air. A pint of oil, when burnt, produces a pint and a quarter of water; and *a pound of gas, more than two and a half pounds of water*—the increase of weight being due to the absorption of oxygen from the atmosphere—one part of hydrogen taking eight parts, by weight, of oxygen to form water. A London *Argand gas lamp* in a closed shop window will produce, *in four hours, two pints and a half of water*, to condense, or not, upon the glass or the goods according to circumstances."

To say, then, that above 900 lbs. weight of water (nearly half the weight of the ton of coal consumed) passes from the furnace, and by the chimney, in the form of *steam*, though produced by the 5¼ per cent. of hydrogen alone, which the coal contained, may appear exaggeration: nevertheless, the fact is unquestionable, the details of which it is here unnecessary to repeat. They are given in the *Treatise on the Combustion of Coal*. Now, when we consider the enormous mass of steam that would be produced by the vapour of this nearly half a ton weight of water (independently of the nitrogen and carbonic acid), we can readily account for the magnitude of the cloudy vaporous column of the smoke.

The next consideration is, as to the *value of the carbon* which produces the darkened colour of the smoke cloud. Now, the weight of this carbon, in a cubic foot of black smoke, is not equal to that of a single grain. Of the extraordinary light-absorbing property and colouring effect produced by the inappreciable myriads of atoms of this finely-divided carbon, forming part of the cloud of the steam alone, some idea may be formed by *artificially* mixing some of it when in the deposited state of soot with water. For this purpose, *cool down, intentionally*, some of it from its luminous, high temperature, and collect it on a metallic plate held over a candle or gas jet, and touching the flame. Let a *single grain weight* of this soot be gradually and intimately mixed on a pallet, as a painter would, with a pallet knife: first, with a few drops of gum-water, enlarging the quantity until it amounts to a spoonful. On this mixture being poured into a glass globe containing a gallon of water, the whole mass, on being stirred, will become opaque, and of the colour of *ink*. Here we have physical demonstration of the extraordinary colouring effect of the minutely divided carbon—*a single grain* weight being sufficient to give the dark colour to a gallon of water. Whatever then may be the quantity or number of its atoms, we see from the cloud of incombustible matter with which this carbon is so intimately associated, *as smoke*, that even attempting its separation and collection, independently of its combustion, borders on absurdity.

It has already been mentioned that carbonaceous smoke may always be distinguished from gas by the test of applying to it a sheet of paper. Whatever may be the colour of the vapour as it rises from the coal in the retort or on an open fire, *while there is still no flame*, the paper will not be soiled by carbon, simply because it is *inaccessible*, being then in the

first stage, as above shown, and in combination with the gaseous hydrogen. Whereas, in smoke, and after flame has been produced, the carbon, being then separated and cooled down from its state of flame, is encountered (as in the *fourth* stage) in the form of black atoms and will be deposited on the paper.

It may here be noted that the mere motion of the smoky cloud as it ascends in the air, has all the peculiarities of a body of discharged steam with its rolling, ascending, and diffusive character. Its long continuance in the suspended state in the atmosphere is the reverse of what would be the case were it a mere mass of *solid* atoms of carbon. In calm weather we even see this black cloud ascending, vertically, and to a great height—a circumstance that is wholly incompatible with its greater specific gravity, were its atoms unattached to some vaporous or more buoyant body.

In truth we cannot dissociate the ideas of the formation of the two atoms of steam (with their inferior specific gravity), from the simultaneous separation of the carbon with its comparatively high specific gravity,—this carbon being, in volume, as disproportionate to that of the steam, as the car is to the balloon to which it is attached. As regards this disproportion *in bulk*, we know that the volume of each atom of steam is 1,800 times greater than that of the atom of water from which it was formed. Here, alone, then, would be a ratio of 3,600 to one. When, also, we consider the temperature, and high pressure, and consequent enormous expansion of this steam, at the moment of its formation; and passing from the chimney (the atom of carbon, or solid, alone retaining its original diminutive bulk), we are enabled correctly to appreciate the relative volumes of the minute *combustible carbon*, and the *incombustible steam*. Were it possible to examine microscopically this smoke, it would be seen that each atom of the carbon was mechanically attracted by, and adhering to, two or more spherical atoms of steam, possibly multiplying by reflection its appearance and effect as from so many mirrors. We see that by virtue of this adhesion to the atoms of steam, it obtains its ascending power and buoyancy, as *the car does from the balloon.*

Nevertheless, in contempt of chemical truth, and even common observation, we persevere in speaking of the combustion of the cloud of smoke. It surely would be as easy, more rational, and more correct, to speak of its *prevention*. Had even these terms been properly understood, the absurdity of the late Metropolitan Act, for the " combustion of the smoke of furnaces," would have been too obvious to have had the sanction of Parliament.

In looking at the result of imperfect combustion of the carbon of the gas and its conversion into the black element of soot, it may here be observed that the mere waste of so much fuel is insignificant in mischievous agency in comparison to the effect of its deposit in the form of the most powerful non-conductor of heat, in the tubes and flues of the boiler,—thus effectively neutralising their value as heating surfaces. Those, therefore, who insist on asserting that smoke is a combustible, and may be burned, should be prepared to show how this cloud of watery vapour and gaseous matter can be separated from its minute complement of carbon; for, until that separation is effected, it is as absurd to speak of the combustion of the *cloud of smoke*, as it would be of converting the air in the *cloud of dust*, which blows along our streets, to a profitable manure for the mere sake of the particles of solid matter which it holds in suspension.

Looking, then, at this cloudy mass with reference to combustibility, we see that since the separation of the carbon from its accompanying cloud is practically impossible, its combustion is equally so.

Finally, we see that the cause of the formation of smoke is, the absence of the proper supply of air to the combustion of the gas (the only combustible that it contains), *at the time when from its high temperature of incandescence* it was best fitted to receive it. So long, then, as due consideration to the providing for the admission of this supply of air to the furnace, at *the proper time* and in the proper quantity, be but little attended to; and that our practical engineers regard the question as of secondary importance, or almost with neglect, we cannot expect any reformation of the system of furnace details and arrangements,—yet the presence of the *air* in the *dramatis personæ* of combustion, concurrently with that of the *fuel*, is as essential to the proper *denouement* in the furnace performance, as would be the presence of both the hero and the heroine to that of a theatrical drama. We can no more dispense with the *exits and the entrances of the air and the fuel* in the one case, than with those of *Hamlet* and *Ophelia* in the other.

SECTION VIII.

OF THE EXPENSE OR ECONOMY IN ERECTING AND WORKING THE SEVERAL PLANS.

On this head nothing can be determined, nor any reliable results obtained, even from the statements of the patentees themselves. Assertion is met by counter assertion. Certificates of success are followed by equally creditable statements of failure; and as the causes of either are, in no instance, explained or examined, no means exist for obtaining any information either as to expense or economy. The result is, that the manufacturing public are perplexed. They are not experimenters, out of their proper spheres, and are thus left at the mercy of the most plausible smoke-burning pretender. In this way, manufacturers are often led to allow patentees to begin their operations, or alterations of furnaces, and subseqently find themselves involved in a heavy expenditure which they have no way of avoiding.

In one case which came within the knowledge of the writer, a person, wholly illiterate, had, nevertheless, the address some years back to obtain credit for ingenuity as a hot-air and smoke-burning patentee, not only with many manufacturers, but even with the Admiralty, and to be allowed to introduce his apparatus at a considerable expense and detention into a Government vessel, the Urgent, at Woolwich; and had also obtained an Admiralty order to introduce his supposed patent (for he really had none) into her Majesty's yacht, but of which, subsequently, he did not avail himself. The writer watched the whole proceedings during some months, and it is needless to say it was attended with absolute failure. Considerable expense was incurred, and the whole was ultimately removed: no investigation, however, followed, nor was the public informed either of the cause of failure or of the fact itself. The so-called patentee, however, continued his deceptive statements and advertisements, still asserting that he

could burn the smoke and save 20 per cent. of the fuel,—the parties injured being often well pleased to pay his charges (in one case to the amount of £50), and get rid both of the man and his apparatus.

Of the expense in erecting and working any of the proposed plans, nothing reliable, therefore, can be stated. Where complicated apparatus or mechanical power is employed, with troublesome alterations of flues and furnace setting, not only must the first cost be proportionate, but the moving power must also be taken into account, together with the "Royalty," or other source of profit to the patentee. In general, the heavy sums charged bear no proportion to the actual outlay; yet the patentee must be remunerated, and the mode of remunerating him by a "Royalty" has been adopted.

Now, when it is considered that perfect combustion depends, exclusively, on the mode and extent to which the *combustible* and *the air* are brought together, as in the ordinary gas burners, and the simple means by which this can be effected, there can be no justifiable room for any heavy cost. The use of a few perforated iron plates, bricks, or fire tiles, containing some 400 or 500 orifices, cannot exceed a moderate expense.

The enunciation, however, of that fact at once raised a hornet's nest of opponents. All possible injury and destruction of the boilers, as already mentioned, was predicted as the inevitable result of admitting cold air. Patentees, whose sole object was the obtaining a livelihood, could not reconcile the introduction of a more simple or less costly apparatus. There was no profit to be made by such, and the whole community of mechanical inventors, speculative patentees, and furnace builders, were soon in open hostility to a principle which left no margin for high charges. Nevertheless, many have since wisely, though silently and unacknowledged, made such the basis of their respective patents, adding more or less complicated, but unnecessary, machinery to justify their claims to originality and patent right.

SECTION IX.

OF THE PRACTICAL APPLICATION OF THE PRINCIPLES HEREIN EXPLAINED.

In illustration of the principles described in this essay, and to give the whole a practical bearing, the following section is accompanied by explanatory drawings, from which the engineer and boiler-maker will see how cheaply and simply these principles have been successfully applied.

To enable the mere owners of furnaces *of themselves* to remove the smoke nuisance from their own premises, or expect that any specific or general law, could be laid down to meet the endless varieties of malconstruction of furnaces that occur in practice, would be as impossible as to give rules by which every man might become his own physician and correct the derangements of his own bodily system, or become his own architect or engineer. The public cannot be acquainted with the principles on which chemical action and combustion depend, and which decide the question of a well-proportioned furnace or boiler, much less to reduce them to practice. It would be deceiving ourselves were we to expect that any but engineers or professional persons, designers of the various classes of furnaces and boilers, could give them the necessary attention. With the view, then, of enabling such to avoid those antiquated errors which sounder views and more enlightened practice have pointed out, the following observations are here offered.

It continues to be asserted that the "whole question of furnaces and boilers is one of mere *dimensions*." This error demands attention. Its authors forget that there is the *previous question* to be decided—namely, *how these dimensions are to be ascertained?* This can only be solved by inquiry into the *purposes* which such dimensions are to effect. *Scientific examination must, therefore, take the lead,* and determine the proper mechanical proportions and details of those vessels in which combustion is to be effected. We must here bear in mind that in the furnace we have to provide for the combustion of *two distinct classes of fuel,* namely,—the *gaseous* and the solid, or coke part of the coal. As regards the latter, we need not here stop to examine the conditions of its combustion, inasmuch as it has no connexion with the question of smoke;—our business is with the former.

The time is within our own recollection, when, to have spoken of the combustion of the *gaseous portion* of coal, apart from the *coal itself,* would have been unintelligible. We of the present day are, however, so familiar with the use of the gas from coal, both for illuminating and heating purposes, that such distinction is not only unobjectionable, but absolutely necessary, when treating practically of the use of coal. In speaking of this process, as we would of any other, from chemical to culinary, we have to consider,—First, the *quantities* of each ingredient employed,—and secondly, — *the mode* of bringing them together.

In the case of the furnace, our task is easy. We have but *two* ingredients to deal with,—namely, the *gaseous fuel and the air.* To say that *precise quantities of each* are necessary to obtain a given result, is only to say what is common to all processes. This may be illustrated by the reference to the action of the lungs. The blood circulating through the *lungs* requires a given quantity of air in promoting respiration and sustaining life. The same law prevails in sustaining combustion in the *furnace.* In the former the ingredients are the *blood and the air* —in the latter, *the gas and the air.* As regards *the lungs,* we are told by authority[1], that about 150 ounces of blood are propelled into the lungs *per minute,* and that the quantity of air to be inhaled in the same time will be about 400 cubic inches As

[1] "The lungs, in their totality, are more vascular organs than any other parts of the body; in fact, in a given time, they receive precisely the same amount of blood as the whole of the rest of the system. At every time that the heart beats it sends by one of its cavities —the right ventricle—*into the lungs two ounces of blood;* whilst by another of its cavities—the left ventricle—it drives into the body an equal quantity of the vital fluid. The heart beats, upon an average, about 75 times in a minute; so that in that period of time 150 *ounces of blood are propelled into the lungs;* in the course of one hour, 562 pounds, and in twenty-four hours, 13,488 pounds, or above 24 hogsheads. Such is the enormous amount of blood circulating incessantly through the pulmonary texture. The quantity of *atmospheric air* admitted by the wind-pipe is *proportionately large:* at each time we inspire there enter into the lungs about 20 cubic inches of air, and there being 20 respirations in a minute, 400 *cubic inches of air enter in that time,* 14 cubic feet per hour, and 366 cubic feet, or 36 hogsheads, per diem. Now, what, it may be asked, is the object of this vast amount of liquid and gaseous matter being sent to the lungs? It is essentially to purify the blood by unloading it of carbonic acid."—Lecture delivered at Liverpool and Manchester on the Unhealthiness of Towns, by R. D. Grainger, Lecturer on Physiology at St. Thomas's Hospital.

regards *the furnace*, each hundred pounds weight of coal produces about 500 cubic feet of gas,—each of which requires the oxygen of ten cubic feet of air—thus:—

75 pulsations	= 150 ounces of blood	= 400 cubic inches of air.
100 lbs. of coal	= 500 cubic feet of gas	= 5,000 cubic feet of air.

As these laws of nature cannot be dispensed with, how faulty must be the practice which overlooks this necessary consideration of *relative quantities*, and the inattention to *one out of the two* ingredients employed,—namely, *the air*.

The usual custom on coal being thrown into a furnace is to close the door, the air being thus *absolutely excluded*. Yet, with equal consistency might we close the passage of the air to the lungs. Conscious, however, that air is necessary, but without inquiry, and regardless of the *quantity* for which access should be provided, it is taken for granted (and even still insisted on by many), that enough will pass to the gases above the fuel (*from the ash-pit upwards*), through the incandescent portion of the preceding charge, and the further body of each fresh charge. The error and impolicy of this has been already and conclusively decided by Professor Daniell, in his letter inserted in a preceding section. A moment's consideration should have suggested that the air, so entering, would have *its own special duty to perform*, namely,—the effecting the combustion of that incandescent fuel:—and further, that the largest quantity of combustible gas would be generated from each new charge, at the very time when the quantity of air that could possibly pass through such two bodies of superincumbent fuel, would be most restricted, and *utterly unequal to the demand*.

It has been shown (section 6) that in round numbers *the gas* of a ton of bituminous coal measures 10,000 cubic feet, requiring 100,000 cubic feet of air, while *the coke* portion of the same ton weight will require a further amount of at least 200,000 cubic feet —the gross volume of 300,000 cubic feet being thus absolutely required for the use of each ton of coal, independently of the *excess*, or double quantity, referred to by Professor Daniell.

The next consideration is how these two large quantities of gas and air can be best brought into contact, and in this lies the important feature as regards the non-formation of smoke. On this we may again refer to the lungs, and learn a lesson from Nature. The lungs, in their wonderful structure, are so constituted that the air is enabled to perform its functions by virtue of that *extent of surface* which their cellular character affords. One of the highest and most recent authorities, Professor Lehman, observes:—

> "The mechanical momenta of the action of the lungs depend upon the *manner and the degree* in which the bodies acted upon (videlicet, the blood and the atmospheric air) are brought into contact with each other. That the elastic atmosphere and the liquid blood are separated by an extremely delicate moistened membrane. Although the interchange may be somewhat retarded by these membranes, Nature has compensated for these impediments by giving an extraordinary degree of *expansion to the surface of contact*. The extremely delicate distribution of the blood and air vessels affords an *immense extent of superfices in a small space*, and enables the processes to be widely diffused."[1]

Doctor Reid observes, of this extent of surface, that 400 square feet may be taken as near the truth.

The analogy between the means by which the *air and the blood* are brought into contact in the lungs, and the *air and the gas* in the furnace, is highly instructive. In the former, the process is effected in the short period of each inspiration by the extraordinary *extension of superfices* and means for obtaining individual contact. So in the latter, in imitation of Nature, we should, as far as possible, increase the means of contact between the atoms of the air and the gas. In both, mechanical expedients are necessary to counteract or compensate for the *shortness of time* allowed, arising, in the lungs, from the rapidity of inspiration and expiration: in the furnace, from the rapidity of the draught and current through it. It is to this rapidity (and which can only be counteracted by mechanical appliances) that the attention of the practical engineer should be directed, seeing that we have no provision in the furnace such as Nature has given the lungs by their cellular construction. Were the lungs to be merely filled with air, as if they were a jar or a bladder, they would be utterly insufficient for their necessary functions: so, the mere filling the furnace with air would be equally insufficient for producing that mixture and diffusion on which combustion absolutely depends.

It has been already shown that in an Argand gas lamp the surface for contact is obtained by the *gas issuing into the air* through numerous small orifices. In the furnace, to effect the same purpose the engineer has only to reverse the arrangement by causing the air to issue to gas within the chamber by *numerous orifices, and in divided streams or films*, thus mechanically expediting the necessary mixture and contact. By this means, even for the largest furnaces, the air may be so introduced that instantaneous combustion will be effected as each jet or atom of air is introduced. This is truthfully indicated by the pyrometer.

Take for instance the class of furnaces which are largely instrumental in creating the smoke nuisance where there is neither boiler nor steam, and which are used for *heating iron plates and bars* (a drawing of such furnace which has been in operation during the last ten years will be hereafter given), showing how the principle has been successfully reduced to practice.

By attention to the conditions here to be pointed out, the designers of furnaces will be enabled correctly to determine the formation and relative proportions of the several parts, with reference to the functions of each. In the absence of such inquiry, however, certain empyrical laws are laid down, and determined by the *slide rule* (see *Treatise on the Combustion of Coal*, Chap I. page 44). This is attempting to decide the *mechanical proportions* of a complicated vessel before ascertaining the *purposes* for which it is intended. It is here proposed to reverse this practice, and begin by considering the respective *duties* which each part of a furnace or boiler has to perform, and from these to determine, practically, their relative sizes, areas, and other details. These will be examined under the following heads, viz.:—

1st,—Of the *chamber* of the furnace and the area *above* the fuel.

2nd,—Of the ash-pit and the area below the fuel.

3rd,—Of the means and mode by which the air should be admitted to the gas in the chamber.

4th,—Of the required quantity of air in reference to *the draught*.

5th,—Of the passages through which *the products* of combustion are carried away.

6th,—Of the distance, length of flue, or run, along which the products have to travel.

[1] *Physiological Chemistry*, by Professor C. G. Lehman, printed by the Cavendish Society.

The mere enumeration of these necessary heads shows how fruitless would be the attempt to qualify the public, or those who ask, what they are to do. In correcting the imperfections of their own smoke-making furnaces, and which may probably be erroneous in many of these particulars.

1st,—Of the area or space in the chamber of the furnace above the fuel.

In this chamber the gases have first to be generated from the coal; then to be brought into the necessary contact with the air; and further to undergo the first process towards combustion, namely, the conversion into flame; and all within a fraction of a second of time. Here are both mechanical and chemical reasons for providing an *enlarged chamber*,[1] nevertheless, the prevailing and erroneous practice, is, to make it *long, narrow, shallow*, and *cylindrical;* and apparently for the sole purpose of insuring greater strength in resisting the very high pressure now so much advocated.

As a practical rule this chamber, in *square-flued* marine boilers, should have at least eighteen inches in height above the fuel; a greater height, necessarily, being required in *semicircular* furnaces. If the height be less, and the charge heavy, the draught may carry both gas and air into the cooling regions of the flues, before those processes of Nature can be completed, and smoke will consequently be produced. Here, then, in the deficiency of *chamber space*, not in the size of the *boiler*, lies, practically, the cause of the mischief arising from what is called "*forcing the fires*," which Mr. Fairburn justly calls " the *gangrene* which corrupts the whole system"—the mischief of forcing the fires being equally experienced in furnaces where there is no boiler, and consequently, no question of *boiler space* can arise. But there is another gangrene which has a prior claim on our reprobation—namely, the constructing boilers with furnaces so limited in their flues and several areas, as to render this *forcing and heavy firing* absolutely necessary for obtaining the required quantity of heat and steam. For how can we reconcile the placing furnaces with grates of 6 or 8 feet in length, in semicircular flues of but 2 feet or 2 feet 6 inches in diameter?

On this point of forcing there is, practically, much misapprehension. When we speak of "*want of boiler space*," or "*forcing the boiler*,"—we really mean want of *furnace* space, and forcing *the fires*. We cannot force a *boiler;* but we may force the action of the *fires*, as we would an open house grate, by continually stirring and charging, and thus increasing the quantity of coals consumed in given times. By stirring up a large charge of coal, a greater evolution of gas is produced than can be supplied and mixed with air *within the time available;* consequently, much will pass away in the form of unconsumed carbon or smoke. *Forcing the fires*, then, may be as injurious with *large*, as with *small boilers*.

2ndly,—Of the area of the *ash-pit*, below the fuel. Here we find a similar error in making this *long* and *shallow*. The proportions as regards the chamber may be considered applicable to the ash-pit,—the object being to enable the air to rise with a *moderate velocity equally to all parts of the fuel and bars*, and thus avoid an objectionable current towards the *back end*, by which the incandescent fuel would be there more rapidly consumed, and the bars consequently become uncovered. This is a far more important circumstance than is usually supposed; for if the bars be not equally covered, and particularly at the sides and back end, the air will there enter in uncontrolled quantities, defeating all arrangements for its regulation.

3rdly,—Of the *mode* by which the air should be admitted to the gas in the furnace chamber.

If the air be admitted *in a body*, as when the door is opened, a cooling effect will be the result. To avoid this, it will be seen by the accompanying drawings how the air should be admitted, in a divided state, through small orifices, though sufficient in number to allow the *gross* required quantity to pass inwards at a rate not exceeding 5 *feet lineal per second*. This rate has been practically ascertained. To apply this, take the case of a furnace having 12 square feet of bar surface (say 5 feet by 2 feet 6 inches). If the draught be active, there should be an area for the introduction of the air of about 5 *square inches for each square foot of grate surface:* or, in the gross 60 *square inches*. The estimating these proportions has been the result of long experience. Taking, then, 5 *half-inch* orifices as equal in area to 1 *square inch*,—300 of these orifices should be provided for a furnace of such dimensions.

It has been proved, that it is a matter of indifference where these air distributor orifices may be placed, provided they secure the admission of the air to the flame *before its temperature is too much* reduced, and the carbon has entered the *fourth stage*, as already explained, or smoke will be formed.

In the case of *multitubular* and other *short* boilers with short runs, the orifices may be judiciously placed in the *door box*, or surrounding it, as is shown in several of the accompanying drawings. Should there not, however, be sufficient space in that quarter for the required number, a portion of them may be introduced through a perforated distributor box fixed in *the lower part of the bridge*. In both these ways the principle has been applied during many years in the furnaces of numerous land boilers and steam vessels;—in several of the mail contract packets, and in other large steamers plying between Liverpool, Dublin, and Belfast. Where, however (as is too often the case), radical defects exist in the construction of the boilers and furnaces, the application of the principle can, of course, be but partially carried out.

This demands the serious consideration of practical men; for, if boilers and their furnaces be so imperfectly constructed that Nature's processes cannot be effected with the rapidity necessary for producing the required quantity of heat and steam, there can be no relief or remedy, and imperfect combustion, with its accompanying smoke, must be the consequence.

4thly,—Of the admission of the required quantity of air in reference to *the draught*.

Here is a point the neglect of which has been the source of numerous errors and failures. To say that the draught is sufficient, is to assume that the *required quantity of air absolutely obtains access.* This, however, involves a serious oversight. The *rate* at which the air passes through the apertures being so much under the influence of the *available* draughts, the introduction of the required quantity becomes a more difficult matter than at first sight would appear. We must, therefore, distinguish between the *apparent* and the *available* draught, and calculate accordingly. The required *number of*

[1] Mr. Murray observes, "a roomy furnace is desirable. As a large furnace is found by experience greatly to facilitate the admixture of the gases, and to ensure their more perfect combustion, as well as to afford the most effective kind of heating surface, it is of great importance that there should be *plenty of room over the fires*."

orifices may be provided, yet the *due quantity* of air may not actually obtain admission through them. In such case (and which is of frequent occurrence in steam-vessels) the gas will be but *imperfectly supplied*, and smoke will be generated.

A case in point may here be mentioned. For the six furnaces of the Prince of Wales steamer, the proper number of air orifices was provided both at the door and the bridge; the gases, however, were still imperfectly consumed, and smoke was continuously made. The engineer, on one occasion, suspecting that the air was obstructed in its approach to the engine-room by injudicious high loading on deck, a temporary apparatus was supplied, worked by four men, by which air was forced, *not into the furnaces, but downwards into the stoke-room and on the level of the floor*. This put the whole to rights. The due quantity of air was then present to enter the furnaces; the combustion of the gas was perfect; the pressure of steam increased; and no smoke formed.

Practically, then, *a deficiency of draught* presents the most frequent, though unsuspected, source of failure, where the proper number of orifices for admission of the air is provided. In steam-vessels, the first cause of a deficient available draught is the *want of height* in the chimney, it being restricted to about 40 feet, although for one-half the number of furnaces *on land* it would have been 120 to 150 feet high. The only alternative, then, is to increase the temperature within the chimney. To procure the required draught there must be either a *high* or a *hot chimney*. Now, a *high* chimney is unattainable in a steamvessel, and a *hot* one can only be obtained at a ruinous waste of heat.

In steam-vessels, the providing an adequate access of air to the stoke-room is not sufficiently attended to. The hatchway, or grating intended for its admission, is usually placed directly *above* the furnace doors and stokers' heads. Yet, as the air in the stoke-room is necessarily over-heated by the large hot boilers, open ash-pits, and the hot cylinders of the engine, the heated air so produced naturally *ascends*, issuing by the very space which had been provided for the *descent* of the cold air. The result is, a deficient circulation, and inadequate available supply of air to the lower part of the stoke-room. In such case, the furnace gases being insufficiently supplied, the stoker has no alternative but *forcing the fires*, by constant stirring and charging, until the furnaces are comparatively full.

But the draught may also be impeded by a restricted area for the *egress of the products*, as well as the *ingress of the air*, as hereafter shown. In such case, the only resource is creating an *artificial draught*, since, unless the required volume of air absolutely obtains admission to the furnace, more or less of the gaseous portions of the fuel must pass away, either as undecomposed and unconsumed *gas* of a *brown* colour, or as unconsumed *carbon*, in the form of smoke, of a decided *blackened hue*. The draught, then, may be artificially increased by *propulsion* or *exhaustion*. This, however, does not belong to the subject of this Essay, and has been fully considered in the treatise *On the Combustion of Coal*.

5thly. Of the passagesthrough which the products of combustion pass from the furnace to the chimney.

These products must necessarily be large, and the more perfect the combustion of the gas, the greater will be their volume. On this head, modern practice is often much at fault. Not taking into account the separate but additional volume of air required for the combustion of the gas of the coal, *the area for draught* has hitherto been much underrated. From a ton of coal, where the due quantities of air are introduced, the volume of its products cannot be less than a *million cubic feet*—considering their high temperature and expanded volume on passing from the furnace—a volume which would fill a tube of twelve inches square, and nearly 200 miles long. It is needless to say that *unless provision be made for the escape of this large volume, the admission of the required quantity of air cannot be effected*.

The first place where egress of these products runs the risk of being obstructed is, in the passage *over the bridge*—the throat of the furnace. At this point, an area should be provided of from *twenty to thirty square inches* for *each square foot* of grate surface, according to the strength of the draught and the quantity of fuel the furnace may contain. In this respect, the practice of the present day is peculiarly erroneous. Numerous instances might be adduced in which this passage is restricted to *one-half*, often to *one-third* the required area. The result must be, that if the proper quantity of air obtain admission to *the gas* in the chamber of the furnace, a commensurate reduction must necessarily take place in the supply by the *ash-pit*. In such case, less coal will be consumed, less heat produced, less gas generated, and less steam supplied. Thus, in correcting one evil—the formation of smoke—from a deficiency of air to the gas, another will be created—namely, a reduction of steam for the engine, caused by deficiency of air by the ash-pit to the solid fuel on the bars.

To put a case of frequent occurrence: suppose the introduction of 6,000 cubic feet of air be required *each minute*;—say, 2,000 for the combustion of *the gas* in the chamber, and 4,000 for that of the incandescent *solid fuel* or *coke* on the bars. Now, if the *throat area* be so restricted that a *gross volume* of but one half, say 3,000, or any lesser quantity than the 6,000 cubic feet can find a vent, per minute, it is obvious that *either the one supply or the other must be reduced below that which nature demands*. Either the *gas* or the *solid* fuel must be insufficiently supplied. In the one case, much of the carbon will pass away in the form of unconsumed gas or smoke; in the other case, there will be a diminished action in the furnace and less coal will be consumed.

Mr. Fairbairn, among his "Recommendations for the Prevention of the Smoke Nuisance," observes, "5thly,—In all cases of active combustion the system of diffusion of air through the *furnace doors, behind the bridge*, or *in both*, should be used to prevent the air having a cooling effect." This is well put, seeing that the same quantity of air when introduced on the diffusion principle, which produces instant and complete combustion, would, if injudiciously introduced in masses through the uncovered bars, or by the door, instantly produce a serious cooling effect.

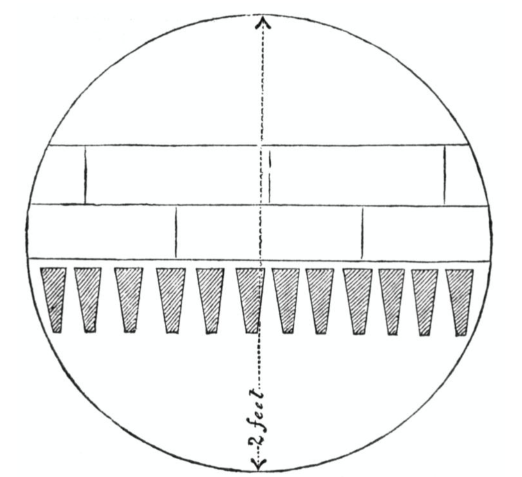
Here we have an explanation of the cause of the stoker's too frequent complaint,—that "when he consumes the smoke he has a deficiency of steam,"—the cause of which he is unable to discover or understand, and which single fact, instead of leading to further inquiry, is often ignorantly set down as the *necessary result* of the admission of the air to the gas. The fact is, the true quantity of air required for the combustion of the gaseous portion of the coal is so little thought of, and so generally underrated, that when the full supply is admitted to *both gaseous and solid fuel*, the gross volume of products is then so

much greater than had been contemplated, that the area for their escape is too frequently found deficient,—a case illustrative of this effect will be given hereafter. This restriction of the area of exit for the products of the furnace is peculiarly incident to the double-flued cylindrical boilers.

To reduce this to practice, — assuming a good draught to a furnace, say, 4 feet by 2 feet, equal to 8 square feet of bar surface, and allowing 24 square inches for each, there should be a gross sectional area over the bridge of 192 square inches, being about 8 inches high, to the crown of a square-topped furnace. Now, suppose the furnace to be enlarged from 4 to 6 feet in length,—making it 12 square feet of grate surface. It is manifest, that in such case, the *throat area* for the enlarged volume of escaping products should *also be enlarged* in a corresponding ratio. That area should then be 12 x 24=288 square inches instead of 192, or, say, 12 inches to the crown above the bridge. This may be taken as the average dimensions of the throat area in marine furnaces.

Assuming then that both the *gas* and the *coke* of the coal entered fully into combustion, the products for which the area of escape *must be provided*, will be about 6,000 cubic feet per minute. Here would seem a simple incontrovertible inference, viz., that the area for exit of the products of combustion should be enlarged in the ratio of the increased grate bar surface, and the quantity of fuel consumed. Strange to say, however, such is practically neglected. Furnaces are often enlarged from 8 or 10 square feet, to 15 *or* 20 *feet, without any enlargement of the throat area for exit,* and which may be taken as the true area that is to decide the amount of available draught.

So extraordinary an oversight may be compared to that of the experimenter who requiring that a vessel containing a gallon of water be emptied in one minute, by a pipe of a given diameter, should nevertheless *double the quantity* of water, and yet expect the vessel to be emptied *within the same time* by the same pressure, and through *the same orifice of discharge*. This certainly would merit the name of sheer stupidity, yet see how near we approach to this in practice. Take the case of many recently-constructed boilers, with cylindrical flue-furnaces, of 2 feet diameter each, as in the annexed figure.



The bars will here occupy 4 inches, and the bridge 6 inches,—thus leaving but 14 inches for both the ash-pit and semicircular throat area, giving but 7 inches in the centre, above the bridge, equal to about 120 square inches. Now this area is not more than would be sufficient for a furnace of but 2 feet long and 2 feet wide. Can we then conceive a case more inconsistent with the simplest arithmetical calculations than making a furnace with so restricted an area, not *two* feet, but *five or six* feet long?

If this be tabulated, we shall see how destructive of all efficiency would be such an arrangement. The following will show what ought to be the relative areas of the throat of a furnace, and its grate-bar surface:—

Supposed length of furnace.	Width.	Gross area in square feet.	Area in inches per square foot of furnace.	Required gross area in inches at the throat.
2 feet	× 2 feet 6 in. =	5 sq. feet.	× 24 inches.	= 120 inches.
3 „	× 2 „ 6 in. =	7 ft. 6 in.	× 24 „	= 180 „
4 „	× 2 „ 6 in. =	10 feet.	× 24 „	= 240 „
5 „	× 2 „ 6 in. =	12 ft. 6 in.	× 24 „	= 300 „
6 „	× 2 „ 6 in. =	15 feet.	× 24 „	= 360 „

This table at once suggests a practical rule for ascertaining the proper area of a furnace grate, viz.—Measure the area of the throat above the bridge in square inches; divide this by 24 (that being the number due to each foot of furnace), and the product will give the correct area, in square feet, which the fire grate should have. So, to ascertain if the area over the bridge be sufficient for the discharge of the products of combustion,—multiply the number of square feet which the furnace may have by 24, and the product will give the area in square inches which should be provided. Let this simple test be applied by any owner of a furnace, and he will soon discover the cause of the prevalence of smoke on the one hand, or the deficiency of steam on the other.

6th. Of the run or distance along which the heated products have to pass from the furnace.

This *distance* may be taken as equivalent to and representing the *time* given for the transmission of the heat to the water. Neither time nor distance, however, can be curtailed, without a commensurate diminution of effect. In this respect, the multitubular system is peculiarly defective, and attended with a wasteful expenditure of heat. The mere increase in the number, or aggregate internal surface of the tubes, is no compensation for the *shortness of the distance and the diminution of time* during which the products are passing from the furnace to the chimney. To this deficiency of run is owing the great expenditure of heat in the locomotive, and in all multi-tubular boilers.

Of the error of estimating the gross internal area of the tubes as so much heat-transmitting surface we need no other testimony than that of the tubes themselves, since, in breaking up old boilers it is not unfrequently found that many, and even one-half the number, appear to have never been brought into action. In truth, in tubular boilers using bituminous coal, the tubes, *as steam-generators*, are comparatively of little value, and the tubes may be considered merely in the character of *checks*, to prevent the too rapid passage of the products to the chimney, owing to the shortness of the run and time allowed. A drawing will hereafter be given specially applicable to this point.

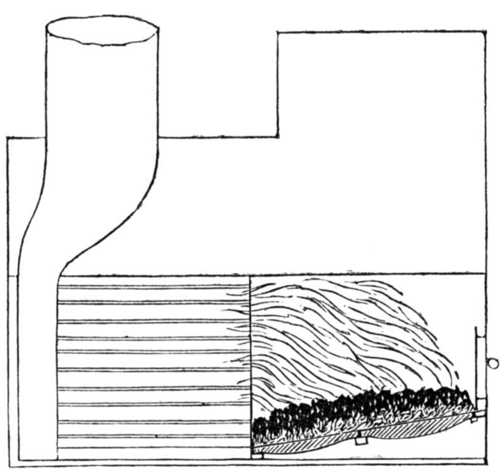
This being the ordinary case in marine tubular boilers, the result is, that the generation of the steam is confined, almost exclusively, to the plate surface in immediate connexion with the furnaces, with the necessary accompaniment *forcing the fires;* while the

heat that would have been produced under a moderate rate of firing, had the gases been brought fully into combustion, is necessarily lost in the form of smoke, with the serious disadvantage of lining the interior of the tubes and smoke-box with a coat of nonconducting soot.

As a practical rule, then, from 40 to 80 feet lineal (varying according to the size of the furnace) should be provided between the furnace-bridge and the chimney, along which the heated products travel, giving out heat in their course to the water. If the distance be less (as in the case of *multitubular and short boilers*) there must be a proportionate loss of that heat which should have been available for the generation of steam ; and a larger quantity escaping by the take-up and chimney, necessarily exposing both to the risk of being injuriously over-heated.

Before concluding this section it may be advisable to point to some of those errors of improper areas and dimensions which are of most frequent occurrence. Take, for instance, the case of bakers' ovens. These are not unfrequently placed under the street footway, and in pairs, having the products of the double fires led to an ordinary house flue, with a common chimney pot on it. As these ovens are thus necessarily great smokers, they are frequently complained against, yet their owners never seem to suspect that the main source of the nuisance is the restricted area of the chimney draught.

The following case of imperfect construction merits attention, as being an illustration of the vicious application of the multitubular system. The annexed figure represents one of the furnaces of a steamer

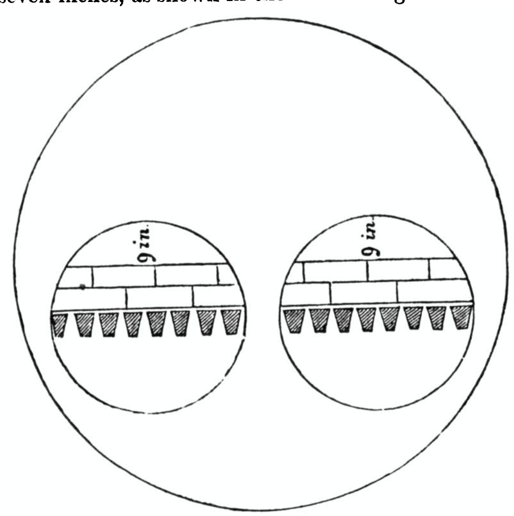


which is an incurable smoke maker. It is 6 feet long, the flame passing into 72 tubes of $2\frac{1}{2}$ inches diameter. The radical defect here consists in the total want of *run*, or distance, by reason of the close proximity of the tubes to the fuel, as in locomotives. There, however, where coke alone is used, none of the evils of smoke or deposited soot can take place. The result of this mal-arrangement is, that *the flame*, with its incandescent carbon, is rapidly forced into the tubes, and into mischievous contact with the refrigeratory products of combustion (carbonic acid, nitrogen, and steam), the carbon being thus, at once, reduced from the high temperature of incandescence, or 3,000°, and converted into the black element of smoke, as shown in the 4th stage. (See section 7.) The mere inspection of this figure shows that neither *time* nor *distance* was afforded for the due mixing of the gas and the air, or the process of combustion to be completed. The remedy here would have been, the removal of the tubes altogether, or, to a distance of 8 or 10 feet from the fuel, accompanied with the raising of the bars to a proper height.

The following case merits peculiar attention from the accumulation of errors brought to light. Messrs. Crossfield and Co., large sugar refiners, having been convicted for a smoke nuisance, employed a person who had previously been successful in the application of the perforated air distributors. In this case, however, he was at fault, and unable to detect the reason why that which in one case, and in his own hands, had been all-sufficient, should thus prove the reverse in another.

Although the furnaces caused much smoke, the stokers, by hard firing, were enabled to produce the required pressure of steam. On the admission of the air, however, through the perforated box in the door, as hereafter shown in the accompanying drawings, the *gases were effectually consumed*, and the generation of smoke prevented. This was, however, accompanied by the evil already alluded to—namely, a *diminished supply of steam*. Here was a mystery which could not then be solved.

In this state of things the active partner, Mr. Barrow, applied to the writer of this essay, and requested his advice, if possible, to relieve them from the alternative of erecting an additional boiler, or main liable to a monthly prosecution for the smoke nuisance. On examining the furnace, one cause of failure was apparent. The boiler was cylindrical; twenty-four feet long, by six feet six inches in diameter, containing two cylindrical flues of two feet seven inches, as shown in the annexed figure.



In each of these was a furnace of seven feet long, thus giving a grate surface of *eighteen square feet*. With so large a furnace the evolution of gas from each charge of coal was necessarily large, and requiring a large quantity of air for its combustion, with a commensurate throat area for the discharge of the products. Allowing but twenty-five square inches per foot of grate surface for the discharge, at this throat, over the bridge,[1] the area should have been

[1] Mr. Murray, of the Royal Dock Yard, Portsmouth, in a paper communicated to the Institution of Civil Engineers, observes he would "give twenty-six square inches of area over the bridge to every square foot of furnace in which the rate of combustion is 13 lb. of coal on each square foot per hour, and so on in proportion for any grate."

$18 \times 25 = 450$ square inches. Instead of these proportions, however, the actual area was found to be but 189 square inches (see annexed Figure)—equal to $10\frac{1}{2}$ square inches for each square foot of grate surface, instead of 25. This area was manifestly so small that it was impossible that even one half the volume of heated products could be discharged through it, with any ordinary draught.

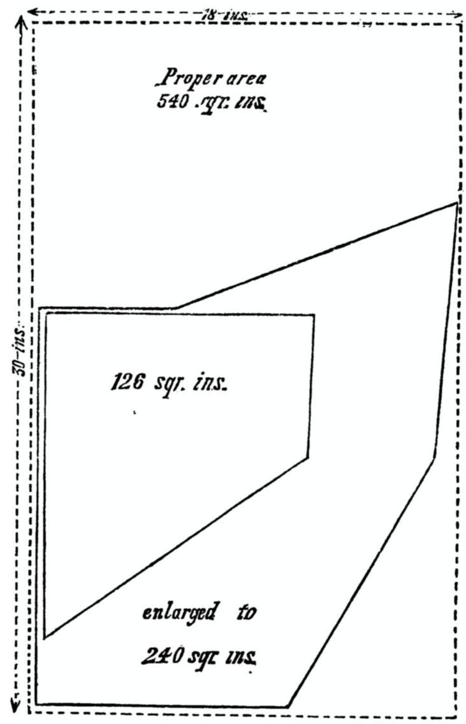
The consequence of this restriction might easily have been predicted, since, when the due quantity of air was admitted to *the gases in the chamber*, a proportionate abstraction from the supply by the *ash-pit* must be the inevitable consequence, thus causing a diminished action in the furnace, less fuel to be consumed, and less steam generated.

In this case there were three modes of relief: either adequately to enlarge the throat area,—to reduce the area of the grate surface,—or to diminish the quantity of products passing over the bridge. The *first* was impracticable from the smallness of the furnace and its semicircular form. The *second* would have caused too serious a reduction in the quantity of steam produced; the *third* plan was adopted by admitting the supply of air to the gases through a perforated distributor placed in the bridge,—thus, in effect, relieving the *throat area* from the products arising from the combustion of the *gas*.

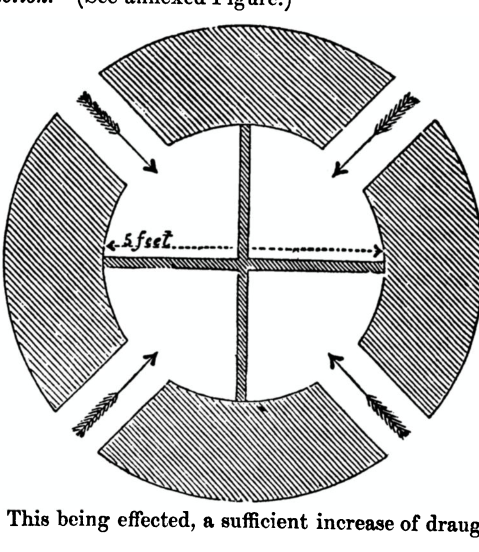
This mode of relief being applied, the advantage, however, was scarcely perceptible, and the evil of a *reduced pressure of steam* still continued. Under such circumstances the ordinary course with most proprietors probably would have been to condemn the system, and pronounce it unavailable. The proprietor here had more intelligence, and he was repaid for his perseverance. As it was impossible that the combustion of the gas, with its *increased volume of flame*, could produce a *cooling effect*, it became necessary to look in some other direction for the decrease in the quantity of steam generated. On further examination a still greater source of error was discovered. This was a remarkably contracted area of exit in the flue leading from the boiler to the main chimney stack. Although each of the two furnaces had 18 square feet of grate surface, and which, at 25 square inches for each, would have required an area of exit of $25 \times 18 = 450$ square inches, this area was actually contracted to 126 square inches, and of the shape shown by the *inner lines* of the annexed figure.

This area was then, but with some difficulty, enlarged, and to the shape and size shown by the *middle lines* of the figure, when it equalled 240 inches. This, however, was still too small for such large furnaces, each of which should have had an area, as marked by the *outside dotted lines*, of 18 inches by 30. Although considerable relief to the exit of the products was thus obtained, its effect was nevertheless unsatisfactory, and even intermittent—a circumstance which still remained to be accounted for.

Not deterred by these difficulties, a further examination was made. The proprietor had observed that occasionally the hot products from some one of the furnaces, instead of *ascending the stack*, which was 80 feet high, appeared to influence the draught of some others of them, forcing *back*, as it were, the hot products out *by their doors*. This, he said, appeared as being a case similar to that described in the *Treatise on Combustion*, quoted from Peclet, where the draught from one furnace acted as a damper, and neutralised that of another; and this proved to be the fact. Having with difficulty obtained access to the base of the stack, the evil was at once manifested. The interior area of the base was but 5 feet diameter, into which four apertures were made for the exit of the products of the two steam boiler furnaces, and two large charcoal heating stoves. These openings being *opposite each other*, as shown in the annexed figure, it was evident that the products from each



would be projected directly *against those of the one opposite*, thus acting the part of a damper on its issue, and necessarily diminishing the draught,—the stronger overpowering the weaker. The remedy was that suggested by Peclet, and well understood by engineers in this country, namely, the interposing diaphragms or cross walls, as shown in the figure, thus giving to each outlet an *independent vertical action*. (See annexed Figure.)



This being effected, a sufficient increase of draught

was produced, and the gases were consumed without the recurrence of the diminution of steam, although the area of exit still remained manifestly too small to do justice to such large furnaces.

In this last case there is a volume of practical instruction as regards areas of *ingress* of the air, and *egress* of the products,—viz., 1st, insufficient area over the bridge; 2ndly, restricted area for draught into the chimney shaft,—and 3rdly, mal-arrangement at the base, as here described. Now, had the proprietor been less intelligent and observant, these furnaces would have remained in the category of impracticables,—furnishing another so-called proof of the assumed insufficiency of the system of admitting air to the chamber gases. It may here be asked, who was to blame for these mal-arrangements, and on whom should have fallen the penalties imposed under the existing law? Was it the designer of the furnace and boiler,—was it the boiler maker,—the engineer, under whom the whole arrangement was made,—the bricklayer who constructed the intermediate insufficient flue, or the architect who planned and erected the chimney stack? Most assuredly the owner of the premises was the last to be visited with penalties arising from these faults of others.

As directly in point, it may be here mentioned that the writer of the paper already alluded to, and inserted in the Society's Journal, gave his views on this subject in the following words:—"To many it appears to be a *very extraordinary thing*, that when smoke is burned less steam is raised in a given time. It seems sound reasoning to say *smoke is fuel* [very *unsound* rather]; and since steam is raised by the burning of fuel, the burning of smoke should raise steam. This is so far correct [very incorrect truly]; but I have observed that in many cases where smoke [gas] is consumed by the admission of air *above*, and not *through* the fuel, there is *not so much coal consumed;* and since coal also is fuel, it is evident that the burning of the smoke may, by decreasing the consumption of coal, lessen the heat of the furnaces, and thereby reduce the quantity of water evaporated in a given time." To comment on such an attempt at reasoning is unnecessary.

But why should less coal be consumed? Here lies the point, which, however, seems beyond the reach of that writer's power of investigation. Can he be ignorant of the fact that the rate of combustion and the quantity of coal used will be in the ratio of the air brought into contact? Instead, therefore, of saying that "there is not *so much coal consumed,*" he should have said, *there is not so much air brought into contact with it*, and then have looked for the cause. This, however, appears not to have been within reach of his philosophy.

Now the really "*extraordinary thing*" here is, that any inquirer, especially one professing to have examined the subject both "practically and scientifically," should have remained satisfied with the crude remark, that "when smoke, meaning gas, is burned, less steam is raised in a given time," and yet make no effort to test the assumed fact, or ascertain the cause of what appeared so contradictory to common sense, —a circumstance which seriously reflected on his own incompetence for such an inquiry.

Had the proprietor of the furnace last mentioned been as easily satisfied, he no doubt would, like too many others, have ordered the perforated air distributors to be removed, justifying himself to the public by stating that he had tried many schemes, and even that of the introduction of the air to the gases, and found them all equally ineffective.

In pointing out the necessity for preparing the furnace and flue arrangements of boilers so as rightly to introduce the air to both the gaseous and solid portions of the coal (that being the main element of economy and efficiency), and obtaining the entire calorific value of the fuel employed, it is here important to discriminate between those classes of boilers which are most favourable, or the reverse, in producing such a consummation. In this point of view, the *Cornish system,* unquestionably, takes the lead. Under that system, as already explained in Section 5, the combustion of the gaseous part of the coal is effected simultaneously with that of the coke part, —*no more gaseous matter being evolved, in given times, than can be supplied with its equivalent of air, under the proper conditions of time and temperature,* and which is the *sine quâ non* of complete combustion.

Now, the direct opposite of this, particularly as regards steam navigation, is, the *short multitubular* boiler, the elements of which are, a short run, short time, large and long furnaces, heavy firing and forcing, large and rapid consumption of fuel, hot chimney for draught, injurious coating of the tubes with non-conducting carbon, or soot, and great waste of heat by the escape of the gaseous element of the coal, unconsumed, and in the form of smoke.

In the adoption of this most wasteful system, in steam vessels, in which (at least for long sea voyages), economy of fuel should be a leading consideration, engineers are equally censurable with the owners. These latter call out for economy of *space*, to meet which, engineers point to the *locomotive*, where the largest power is compressed in the *smallest space.* In this, however, they omit noticing the essential difference between the two classes of boilers,—namely, that in the locomotives, 1st, *coke* is employed, and consequently, there is no gaseous matter to convert into smoke; 2nd, that they have large and lofty furnace chambers; and 3rd, have an adequate *mechanical draught,*—the want of draught being the great drawback to success in large steam vessels.

Had the engineers duly studied the conditions of Nature in the process of the combustion of *bituminous* coal, they would have seen how peculiarly unfavourable to economy of fuel and heat was this multitubular description of boiler, where *smoke making* coal is used, and where the gaseous element forms so large a portion of the heat-generating power.

OF THE DRAWINGS.

The following drawings and explanations are here given with the view of showing how simply, cheaply, and effectually the principle of admitting the air to the gas in the furnace, in a divided state, by means of the perforated distributors, may be applied to all classes of land and marine furnaces.

Fig. 1 represents one of the modes of introducing the air where the mouth of the furnace has been constructed sufficiently wide to admit the required number of half-inch circular orifices. The door boxes are made of cast-iron, and at a small expense. The air enters in front, through a sufficient number of larger orifices, issuing through the greater number of orifices in the back. The left side here represents an *outside,*—the right, an *inside* view of the door-box. In the centre is a sliding plate by which, alternately, the right or left hand *upper orifices* may be opened when the furnaces are charged, and when a larger supply of air is necessary, as a larger development of gas then takes place. This arrangement is, however, *altogether unnecessary when the two furnaces open into one common flue* behind the bridge, and are fired alternately.

Fig. 1.

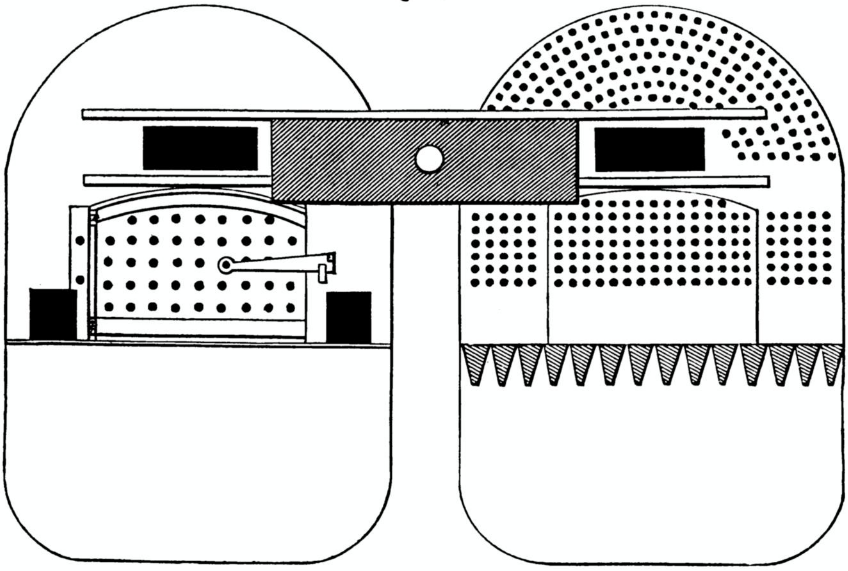


Fig. 2.

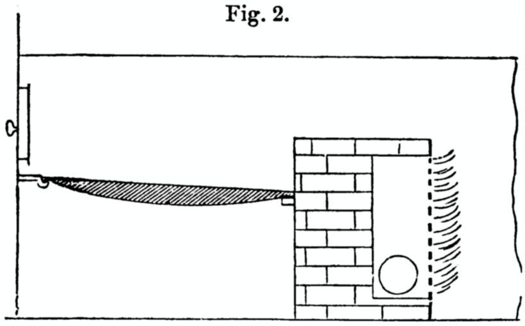
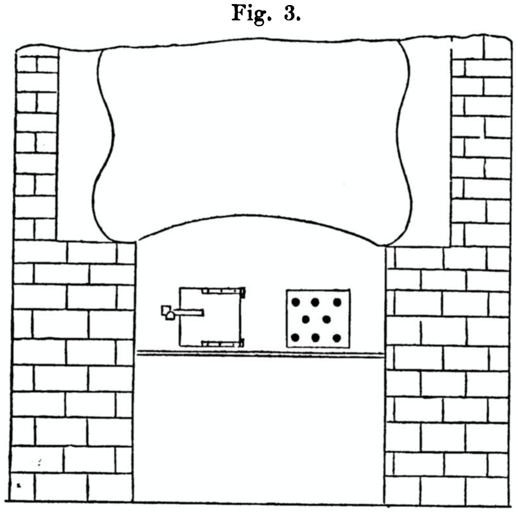


Fig. 3.



Figs. 2 and 3 represent two views of the boiler and furnace erected in 1841, at the Harrington waterworks, Liverpool, and was one of the first land-boilers to which the principle of introducing the air direct to the furnace gas, in divided streams, was applied, under the expired patent of 1839. The chimney was 150 feet high, and had previously caused so great a nuisance in that, the aristocratical part of the town, that a strong memorial was presented to the corporate body, requiring its abatement. The complete success attending this mode of introducing the air produced the following correspondence:—

T. Thompson, Esq., Manager of the Liverpool and Harrington Waterworks Company, Soho-street, Liverpool, 22nd July, 1841, to Mr. C. W. Williams:—

"I have lately had many inquiries on the subject of the patent furnaces, and have, invariably, invited the parties to visit the works and judge for themselves, and I have pleasure in stating, that one and all have expressed themselves not only much pleased, but astonished at seeing the fire loaded with coal, and instead of a dense smoke issuing from the chimney (as is usually the case), finding that which is generally made into smoke, a beautiful flame, giving out an intense heat, and thus saving fuel. Since the adoption of your plan, although we use less coal, we have a larger increase in the quantity of steam."

Extract from Proceedings of the Annual Meeting, 14th January, 1842.

"The Chairman of Directors reported to the meeting, that Mr. C. W. Williams' patent for the prevention of smoke had been adopted at the Company's stations in William Henry-street, Liverpool, and Water-street, Toxteth-park, with perfect success."

During the last fifteen years, and up to the present time, these furnaces have continued in the same effective manner, thus at once disproving the supposed risk of destruction to the boiler plates, as predicted by many at the time. (See Section 4, where this alleged injury is referred to.)

Subsequently, a similar mode of introducing the air was applied to the two furnaces of the stationary engines of the Manchester and Liverpool Railway (now part of the London and North-Western) by Mr. John Dewrance, then the chief manager of the Company's works at Liverpool. This application being equally successful with that stated above produced the following correspondence:—

Liverpool and Manchester Railway, Liverpool, January 17th, 1843.

Dear Sir,—I duly received your favour, inquiring whether I had any objection to give you, officially, a few lines respecting your plan of furnace for smoke preventing. The most official course I considered, would be to refer the question to Mr. Edward Woods,

the company's engineer, and have now the pleasure to enclose you a copy of his reply. Individually, I am happy in being able to add, that your process for smoke burning or preventing, is the most complete and successful in its operation of any that has come within my observation and experience.

I am, dear Sir, yours faithfully,

C. W. Williams, Esq. HENRY BOOTH.

Liverpool, January 17th, 1843.

Dear Sir,—In reply to your letter requesting my opinion of the merits of Mr. C. Wye Williams's patent process for prevention of smoke in furnaces, and inquiring what is the result of my experience in reference to the trial which has been made of it at the Edge-hill station, where it has been adopted in the boilers of the stationary-engine for drawing the trains up the Lime-street tunnel, I beg to state, that I consider *the success of the apparatus complete.* The boilers have been constantly used since November, 1841, and, up to the present time, have not given any trouble nor required repair. The smoke is so perfectly prevented that it is almost impossible to perceive any discolouration of the air over the mouth of the chimney, either when the boilers are in full work, or *after a heavy charge of coal.* The alteration, also, of the boiler of the engine which works the cranes in our warehouses at Park-lane has been attended with equal success. I am, yours, &c.,

Henry Booth, Esq., Treasurer. EDWARD WOODS.

Extract from the Report of Mr. John Dewrance, Superintendent Locomotive Department, Liverpool and Manchester Railway, Edge-hill, Liverpool, 4th October, 1841:—

"One of these boilers (the patent apparatus being applied to two forty-horse boilers, 6 feet diameter and 30 feet long, with fire-flue, 3 feet diameter, and a flue of brickwork round the outside) is now supplying the engine with steam with half the length of the fire-bar (the bars were 6 feet by 3 feet, they are now 3 feet by 3 feet), and we have a clear flame along the flue to the distance of 30 feet from the fire, and the flues, at this distance, are quite *hot:* previous to the alteration this part of the flues was quite *cold.* I may also state that the furnace requires no more than ordinary attention, and that we have a perfect combustion *without smoke.* The saving in fuel is six tons per month; the saving would be double this if the engine was kept constantly at work."

Fig. 4.

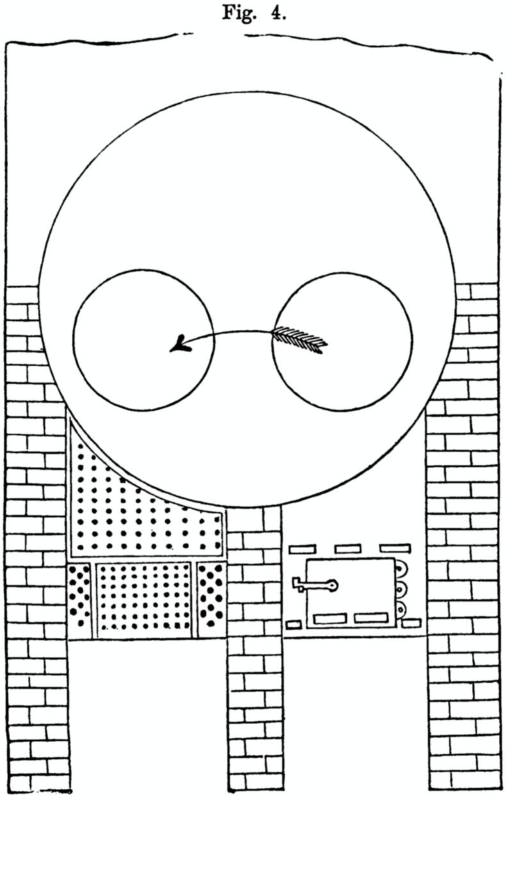
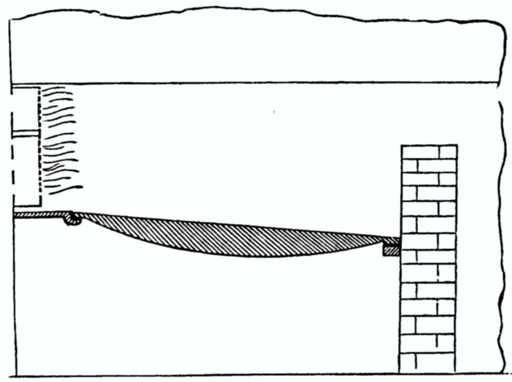


Fig. 5.



Figs. 4 and 5 represent a land boiler suitable for high-pressure steam, and is, in every respect, the most desirable arrangement. The placing the furnaces under the boiler to be charged alternately, secures a sufficiently large furnace chamber, and adequate space for the introduction the required number of orifices, insuring the gentle action of the air among the furnace gases, as water issuing through the small perforations in the rose of the watering-pot.

The furnaces are here separated by a low brick bridge, or division, about 6 inches higher than the fuel, allowing the evolved gases from *both furnaces* to commingle and mix with the air, and thus rendering it unnecessary to give any attention to the quantity of air introduced at the several periods during the continuance of each charge of coal. The air is here introduced to the gases, *above the fuel,* through the perforated distributor box in the door, as in drawing Fig. 1; similar close cast-iron boxes being placed on each side and above it. The right hand gives a view of the *exterior,* the left hand of the *interior* of the distributor boxes.

Fig. 6.

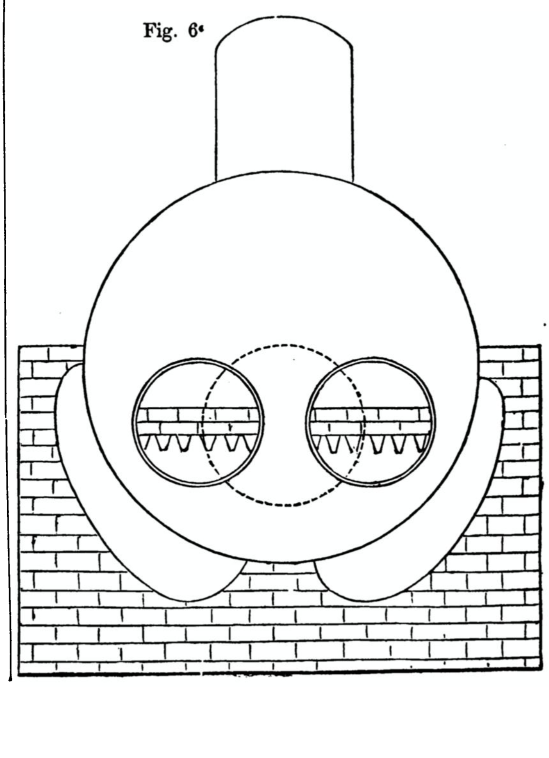
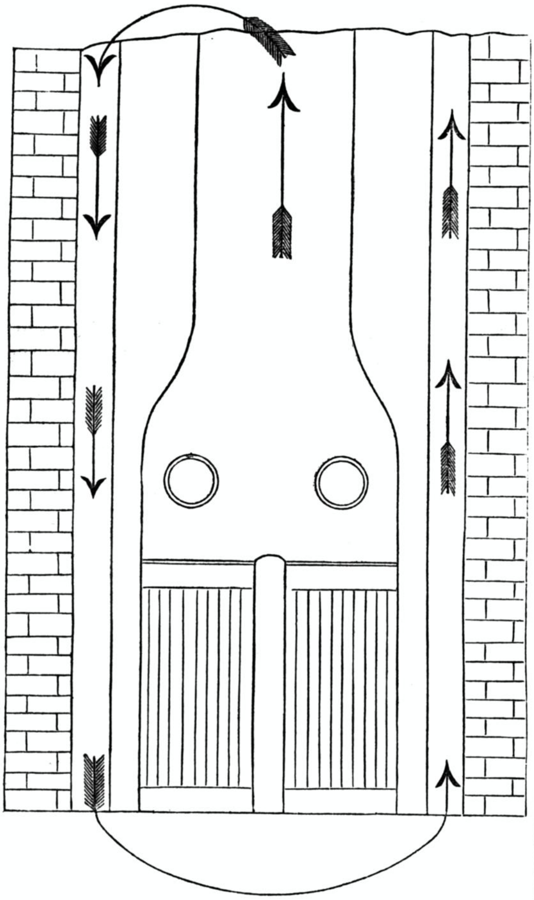


Fig. 7.



These boilers are usually made twenty to thirty feet long. The products of combustion after passing the entire length under the boiler, enter one of the semicircular flues and return by the other to the chimney, thus securing the most effective heating surface with a proper *distance and time* for the transmission of the heat to the water. A pyrometer may here be advantageously introduced into the coolest flue, by which the temperature within may be at all times ascertained. For the explanation and use of this pyrometer see, " *Treatise on the Combustion of Coal.*"

Figs. 6 and 7 represent a land boiler suitable for high pressure. The air is here introduced through the distributor box in the door as already described. Each furnace is three feet wide, placed within the semicircular flue, both uniting in one common flue, described by the dotted line, four feet nine inches in diameter. This arrangement is favourable to the mixing operation of the gas and the air, and the supply through an uniform area without reference to the state of the fuel,—the furnaces being charged alternately.

Fig. 8.

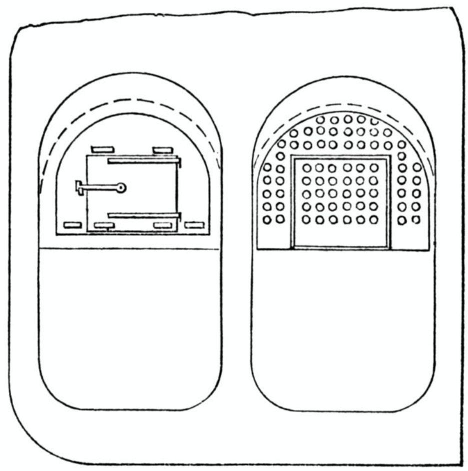


Fig. 9.

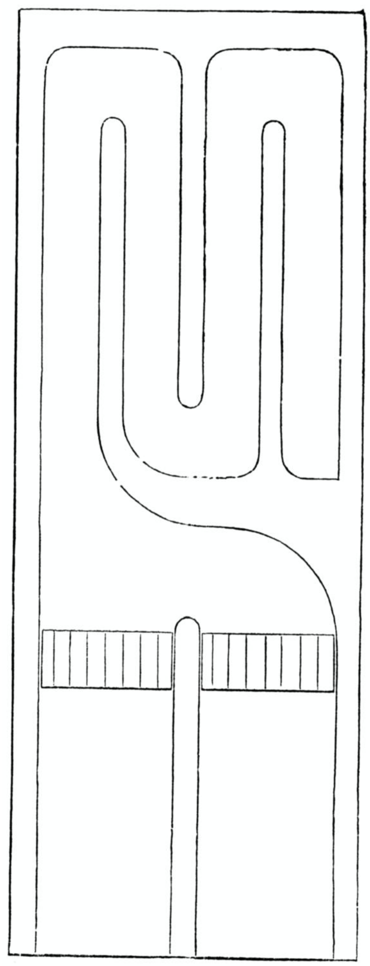
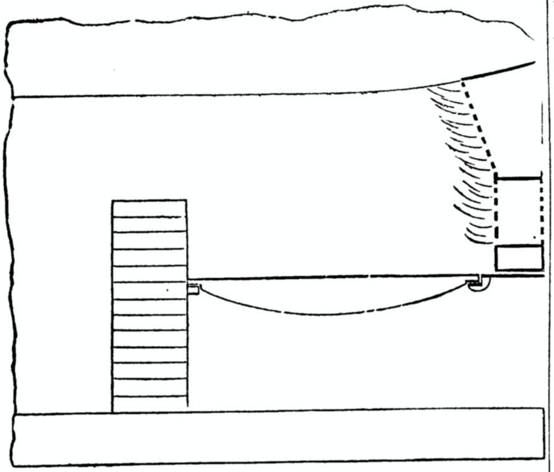


Fig. 10.

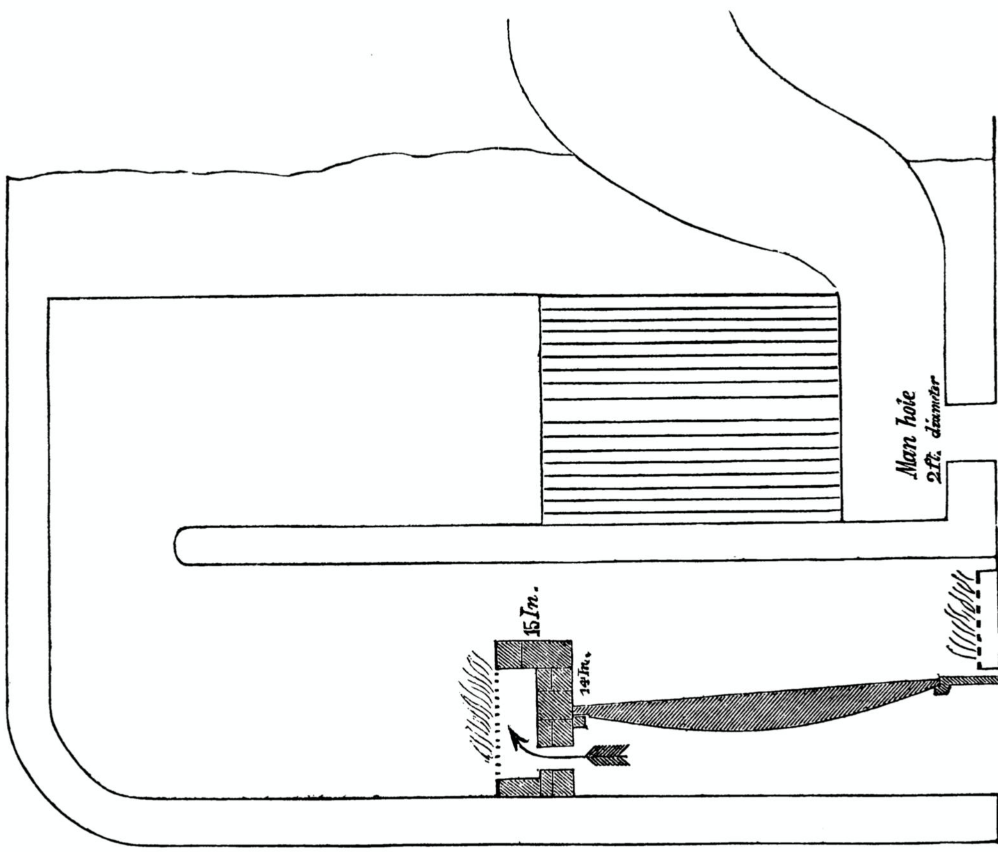


Figs. 8, 9, and 10 represent a marine boiler, the furnaces being in pairs, uniting in a common flue, as adopted during the last 30 years in numerous steam-vessels. The importance of this arrangement is not sufficiently attended to — namely, its requiring no attention to the regulation of the supply of air; since, by charging the furnaces alternately, the supply of *gas* behind the bridge, being at all times *the mean of the two*, it is always *uniform in quantity*, and therefore requiring a *uniform supply of air*.

Attention should here be drawn to the manner in which the door-end of the furnaces is enlarged to allow the required number of orifices to be introduced at *the sides and above the doors*, in opposition to the very erroneous mode of *contracting the mouth-piece* of furnaces, and thus limiting the means of introducing the air orifices at the very place where enlarged space is required. This arrangement, after an experience of many years, continues satisfactory in every point of view, and, in efficiency, may well be contrasted with that of the multitubular. Where the mouthpiece is not sufficiently large to admit the required number of orifices, they may be introduced as shown in drawing Fig. 2.

Fig. 11 represents a marine boiler. The short tubes, as here introduced, check the otherwise too rapid passage of the heated products to the chimney; while the gases, receiving the due supply of air, their combustion is completed before they reach the tubes, and no smoke will be formed. The advantages of this arrangement are, then:—1st, A sufficient space in the furnace-chamber, above the fuel, for the processes of combustion. 2nd, The tubes being at such a distance from the furnace are not exposed to be coated, internally, with soot. 3rd, The areas, both for the *admission* of the air and the *exit* of the heated products, are in proportion to the surface of fire-grate and the fuel to be consumed on it. 4th, Sufficient time and distance are here allowed for the air to

Fig. 11.



become commingled with the gas from the coal, and its combustion is completed before the flame is brought into contact with the refrigeratory tubes.

The disadvantages are merely those which are common to all short and tubular boilers—viz., the run or distance between the furnace and the tubes being so short, much of the products of combustion must necessarily pass into the chimney before their heat can be taken up by the water, and be consequently lost. Again, there is a great depth between the heating surface of the furnaces and the top level of the water, through which the steam has to work its way in its ascent—a circumstance very unfavourable to rapid evaporation.

Fig. 12.

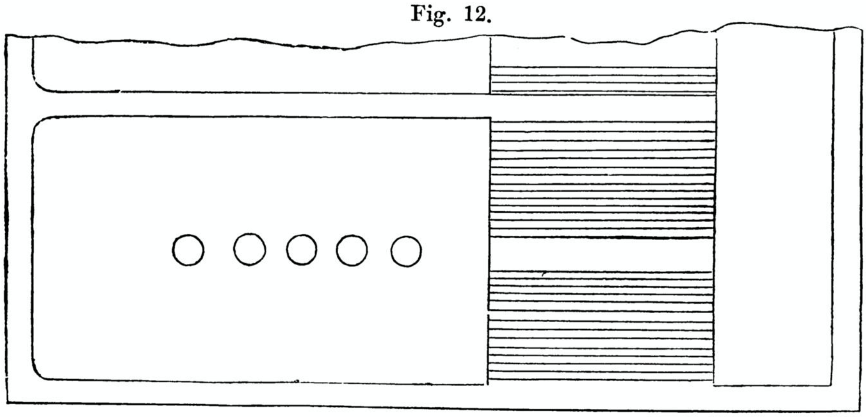
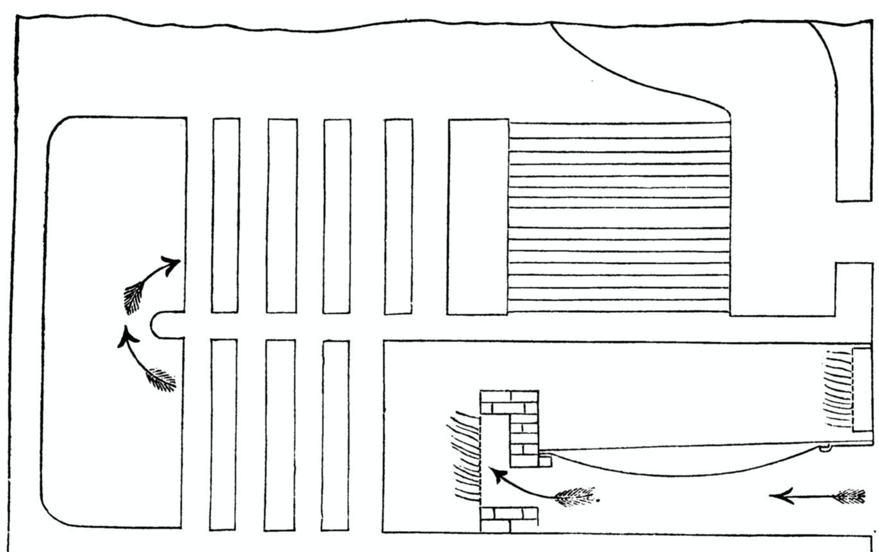


Fig. 13.



The practical and proved advantages of this plan of boiler confirm the views urged in this essay on the erroneous estimate generally made of enlarged amount of *heating surface in the tubes*. One of the latest boilers on this plan is now in the Trafalgar steamer, of 340-horse power. The boiler weighs but 3 cwt. 3 qr. 15 lb. per horse power (tested with 40 lb. water pressure before being used), the usual allowance being from 5 to 6 cwt. per horse power. So of the internal heating surface. That of the flue, or ***plates***, is here 5·5, and of the ***tubes***, 4·1, making a total surface of but 9·6 square feet, instead of 20, ***in the tubes alone***, per nominal per horse power, and which is the usual allowance in multitubular boilers.

Figs. 12 and 13 represent a marine boiler, each of the furnaces being divided by the usual water way, which extends 12 inches beyond the bridge, where the union of the gases and air *from both* is effected, and by which means the supply of gas, being uniform, that of the air may be equally so, as already described. Vertical water stay-tubes are here introduced instead of continuing the water way, to support the roof of both the upper and under flues. These tubes are six inches diameter to allow a free circulation of the water and steam within them, in vertical currents.

The air is introduced, as already mentioned, through the distributor boxes in the door, and around it, and at the bridge.

Fig. 14.

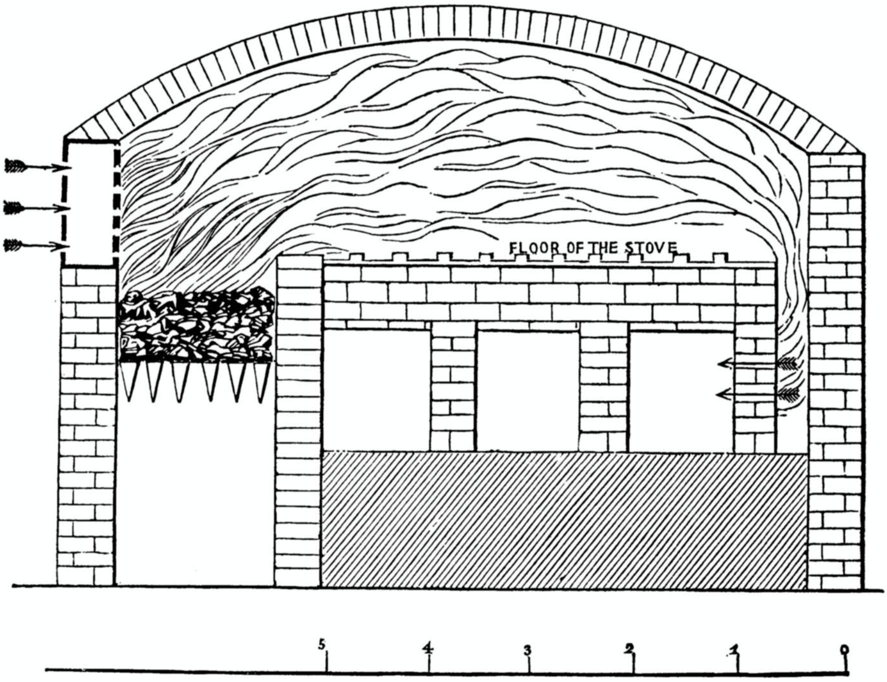
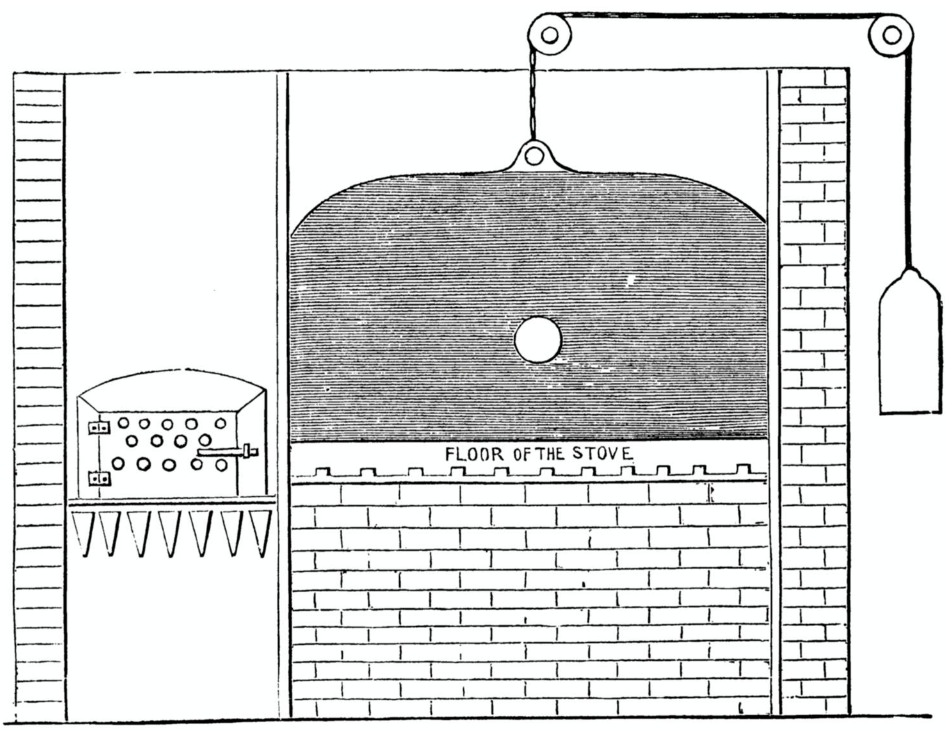


Fig. 15.



Figs. 14 and 15 represent a furnace or stove for heating boiler plates, iron bars, and other large work, and may be made of any required size. These furnaces, as usually constructed, produce much smoke, the coals being laid on the floor of the chamber and there reduced nearly to the state of coke. The plates

to be heated are placed on the fuel, then in a red hot state, and after the main volume of the gas has been driven off in the form of dense black smoke. In the annexed drawings it will be seen the combustion of the coal is effected in a *separate chamber or furnace*,—the plates or bars to be heated being laid on the red-hot brick floor of the stove. The air is here introduced through perforated distributors placed at the side of the furnace chamber, and which may be of any length, furnaces being fixed at both ends. The flame and hot products pass under the arched fire brick roof (as shown by the arrows), which is thus rendered intensely hot, — the heat radiating downwards on the plates. By this arrangement the combustion of the gas of the coal is effected, and no smoke is formed,—the flame causing the roof of the stove to be brought to the proper heat. The products of the combustion are then carried to the chimney by a descending flue, which is so arranged that the heat is also conveyed *under the floor* of the stove chamber.

This furnace has been in successful operation for many years, and has required no repair. An important advantage is gained by this mode of heating,—namely, that the largest stove may be uniformly heated over its entire length.

Another advantage attends this mode of introducing the air, by the facility it gives of using *peat* by itself, or in combination with coal, and by which means the iron is materially improved. So important is this use of peat, that when the stove is heated by it, *cast-iron* furnace bars, when warped, may be here made red hot and then straightened, by which they become as good as when first used.

It will be seen that the same principle and mode of introducing the air is applicable to all classes of furnaces. The above are selected merely as representing those classes which are most frequent on land, and in steam vessels.

SECTION X.

OF THE LEGISLATIVE MEASURES APPLIED TO THE PREVENTION OF THE SMOKE NUISANCE, AND THE CAUSE OF THEIR FAILURES FOR ITS SUPPRESSION.

THE most important legislative measure connected with the smoke nuisance is that of the 16 and 17 Victoria, chap. 128, commonly called Lord Palmerston's Act. It has been already shown that this Act is based on an absolute misconception of the cause of the existence of smoke, or of what it consists, and of the means by which its nuisance may be prevented. So its remedial clauses, being as unwarranted as they are inconclusive, became impracticable in their administration, and worked much injustice in their enforcement.

In the absence of any correct or authorised definition of *what smoke was*, or such as would justify a dictation as to the remedy, the Act, nevertheless, begins by insisting that :—

"Every furnace employed in the metropolis in the working of engines by steam, and every furnace in any mill, factory, printing-house, dye-house, iron foundry, glass-house, distillery, brew-house, gas-works, water-works, or other buildings used for the purpose of trade or manufacture within the metropolis (although a steam-engine be not used or employed therein), shall in all cases be constructed or altered so as *to consume or burn the smoke arising from such furnace*."

With equal propriety or practical effect might the Act have required that every man should consume or correct the impurities of the products issuing from his own lungs; or that he should evaporate the *liquid* portion, and convert to useful purposes the *solid* matter which gives colour to the stream from the sewers of his own premises.

That a blackened cloud of vapoury matter issued from the chimney was a physical fact. It was with this cloud, so far as it was a nuisance, that the Legislature had to deal, and not with the precise character or construction of the furnace from which it proceeded. That confusion and uncertainty prevailed, was evident from the proceedings in the Metropolitan Police Courts. In the case of a prosecution under the Act, and directed by Government, it is reported that after a discussion on the necessity for an inspection of certain furnaces in which the proprietor alleged that *the nuisance was abated*, counsel expressed the readiness of the party to meet any complaint on the part of Government, but that his client insisted there was *no smoke to burn*, as he was using anthracite, or smokeless coal. Mr. Jarman did not consider that *that* was sufficient, for "the Act of Parliament, in the plainest words, required that *furnaces should be constructed in a particular way, and it was immaterial whether smoke came from them or not, if they were of an improper construction.*"

Here it was relied on, that the Act referred to the mere *construction of the furnaces;* and that even the non-existence of any nuisance was no defence. Under such circumstances it was impossible that justice could be done.

Michael Angelo Taylor's Act of 1821 appears to be the first in which the issue of smoke was recognised as a nuisance. Under that act the court was empowered to award costs in case of conviction, but that "if it appears to the court, in case of conviction, that the grievance may be remedied by *altering the construction of the furnace*, it shall be lawful *to the court*, without the consent of the proprietor, to make such order as shall be, by the said court, thought expedient for preventing the nuisance in future, before passing the final sentence upon the defendant so convicted." It need scarcely be observed that such power was not likely ever to be called in operation, and the Act consequently became a dead letter.

In the costly trial of the King *versus* Gott, at York in 1824, the existence of *the nuisance was fully proved;*—a conviction was pressed, with the view of applying for costs; but the judge, Sir John Bayley, "so repeatedly reminded the parties that the Act left him to use his own discretion, and so plainly intimated that that discretion would not be exercised in their favour, that they consented to a verdict of not guilty." The decision of the court, in fact, neutralised the operation of the Act.

Three other indictments were afterwards preferred by the Town Clerk of Leeds. The Grand Jury, after a lengthened inquiry, in each case, found *a true bill.* Nevertheless *the indictments were withdrawn.* It was thus evident that the undefined character both of the offence and the remedy created such uncertainty that nothing effective could be done.

Subsequently, an Act was passed (6th George 4, chap. 132, 1825), for improving the borough of Derby. By this Act it was directed that furnaces, &c., "shall be constructed *in the best manner known and practised*, so as to prevent or consume their own smoke." Here also the same uncertainty was attended

with the same results,—no one being empowered, or able to say, what was the best manner known or practised for "consuming smoke."

All this indecision has been removed by Lord Palmerston's Act, with its peremptory clauses and their manifest injustice. Whatever favourable result has followed, has then been, not in conformity with, but *in spite of, the Act*. In this Act, the describing the furnaces, works, and even buildings to which the consuming or burning process was to be applied, furnishes conclusive evidence that the framers of the Act were themselves unacquainted with the nature of the operations with which they were so peremptorily interfering. The placing in one and the same category the furnaces of a boiler, in which *steam alone* was to be generated, with those in which glass, iron, and other metallic bodies were to be operated on, betrays an unpardonable inattention to the very nature of the disease the Act proposed to deal with.

In this Act, then, we have an *undefined remedy* absolutely insisted on, for an *undefined purpose*, and for an equally *undefined disease*. Under such circumstances, as regards the justice or practicability of its application, it necessarily becomes an absolute failure.

The result of this confusion was that manufacturers, being unable to relieve themselves, were forced into the hands of the speculative patentees as they successively brought their plans into existence, each being ready with his *panacea* to prove that the Legislature were right, and that *smoke could be* "consumed or burnt," no fewer than 77 patents having been taken out for this one purpose in the year 1855. The demand for doctors necessarily increased the supply, and the recent patent law came opportunely in aid of this demand. Under this law, and for a mere trifle, any person can purchase a legal right to the rank of inventor and patentee. The mode of proceeding in too many instances has been, as already exemplified, to look back to former inventions, select the principle of some one or more of them, and by such additions, complications, or modifications, as will pass for originality, the work is done, and the *imitator-patentee* probably reaps an abundant harvest from an unsuspecting public.

When, also, we look to the £10,000 a-year, or other fabulous amount expended in advertising a single invention or nostrum, we have proof that the largest portion of the public, and those who are the least capable of protecting themselves, supply the most prolific field for the successful operation of the balm of Gilead School, in "*smoke combustion*."

Blundering as the Act has been, it has nevertheless "done the State some service." It has compelled manufacturers and others, whose previous indifference to the public complaints was so apparent and culpable *to look into the matter*, and themselves to examine into the cause and effect of the nuisance they created. Here we have the first element of improvement—*inquiry*. Competent parties and chemical professors who have hitherto shunned this subject as the hopeless atmosphere of quackery, are now beginning to be consulted, and truth elicited.

Of local acts for the suppression of the smoke nuisance, it would be a waste of time and labour to examine either their provisions or the causes of their failure. Lord Palmerston's Act, being applicable to the metropolis, has been taken as a precedent for other towns. In the amended Liverpool Sanatory Act for 1854, the smoke nuisance clauses are a verbatim copy of the former, with the same unmeaning title — viz., "*Furnaces to consume their own smoke*,"—a title utterly discreditable in this age of practical science and progress.

With reference to the failure of these Acts it is traceable in all to the one cause—namely, the undefined character of both the nuisance and the remedy, and the visiting the penalties on the wrong party.

Before the adoption of legislative measures, the first step should have been a well-conducted series of experiments, and a deliberate *scientific* examination of the subject; instead of which, however, the Act enters into the Quixotic region of imagination, directing that the cloud, called smoke, shall be actually "consumed or burnt," although without any examination, authority, or proof, that such was practicable. Parliamentary Committees are manifestly unequal to the subject, and incompetent to decide, or draw any inference from such a mass of contradictory evidence as they must necessarily have to deal with.

On the measures taken by Government it is unnecessary to comment. Dr. Ure, in the last edition of his *Dictionary of Arts*, under the title "Coal," has sufficiently pointed out the grave errors committed in one department of their inquiry.

An observation may here be made on the *description of furnace and boiler* constructed for what was called the Parliamentary experiments.[1] It is only necessary to add that it was deficient in all that could enable an operator to arrive at any safe or intelligible conclusion. No means were afforded of ascertaining, by pyrometer or otherwise, the amount of *heat generated, applied or lost*. No analysis was made of the products of the combustion, under varying modes of management. No means were provided for observing what took place *within* the furnace, to enable the experimenter to distinguish the changes or processes going on, and no provision whatever for that most important of all the conditions of combustion, namely,—the *admission or regulation of the air*. Nothing was done to test the quantity introduced, or what theoretically or practically would produce the best effects. Yet all these are not only absolutely necessary, but as capable of being ascertained, as we do the temperature or weight of the atmosphere by the thermometer or the barometer.

Before concluding this Essay it may be advisable to offer some remarks as to the remedy.

OF THE REMEDY.

In connexion with this branch of the subject, the question of *remedial measures*, as far as they are within the scope of legislation, necessarily forms an important feature. Before legal penalties can lead to any practical good, the public should be informed how they may be avoided. The imposition of fines may be effective in preventing the commission of a moral wrong, but to punish one man because he is not as skilful or scientific as another, would be downright tyranny. To attempt, therefore, to compel

1 Mr. Murray has given the following description of this boiler: "It was made on the Cornish principle, being cylindrical, with flat ends and an internal flue within which the grate was placed at one end. The hot hair and gases, after leaving the furnace, passed through the central flue to the other end of the boiler, where they *divided into two streams* and returned to the front of the boiler, along the outside by a flue on each side. These two *were then united again* under the front of the boiler and returned along a flue under the bottom of the boiler, finally entering the chimney after a course of about 36 feet. The grate surface was five square feet and the total heating surface of the boiler 179 square feet. The boiler was worked under a pressure of from 1 to 3 lbs. on the square inch."

him *to "burn the smoke"* from the chimney of his manufactory, without informing him *how it is to be done, or* whether *it be even possible*, would be as unjust as unavailing. Again, to tell the manufacturing community that they must not only prevent the issue of smoke from their chimneys, but must do it in a special manner, namely, by *burning it*, is as arbitrary a violation of common sense as of scientific knowledge. If it be an indictable offence, that a furnace produces a volume of smoke, the penalties for such should, in common justice, attach to *the maker* of such furnace, not to the innocent *purchaser or owner*, at least unless he be informed how they could be avoided. Until such be the case, there can be no practical abatement of the smoke nuisance. Schemes for temporary alleviation may be applicable to special cases, but until remedial measures go to the source of the evil, it must continue to exist.

By the preceding sections we see the nuisance of smoke arises in general, from the mal-construction of the furnace, flues, &c. Who, then, it may be asked, are the parties, and on whom does it lay, so to construct them that such malconstruction shall be avoided?

The engineer who designs and constructs a steam-engine , with its boiler, furnace, and appendages, should be responsible, rather than the miller or manufacturer who may be the mere purchaser. Let the law provide a *summary process* for obtaining redress, and the evil will soon be abated. The public will then be at once enlisted in the cause of suppression, instead of being sympathisers with those on whom the penalties now so unjustly and arbitrarily fall. This will be a practical measure of *prevention*, instead of a fruitless attempt at *cure*.

It is surely enough that the unoffending owner of a smoke-making furnace, as in the case referred to in the last section, has to pay the penalty of a wasteful expenditure of fuel and cost of alterations, without being subject to a prosecution for a nuisance which he was no way instrumental in creating. Among the recent convictions by the magistrates of Liverpool, one, among many similar cases, may here be mentioned as illustrative of the hardship, and even injustice, arising out of the construction and arbitrary terms of the Act.

Mr. ———, a corn-miller, on being indicted for the unquestionable nuisance of a continuous emission of dense smoke from his chimney, pleaded that he was not the author or cause of the evil complained of, and which he had no means of preventing. He said he knew nothing of engineering or boiler making, or how smoke was to be consumed; that the Act had not stated *how that was to be effected;* and that high chemical authorities had even stated that smoke was *incombustible*. He had ordered a steam-engine and boiler from an engineer of eminence, but no sooner was it set to work than his neighbours complained of the nuisance it created. He was willing to adopt any remedy the magistrates might direct. On what principle of justice, then, he asked, should *he* be made accountable for the errors of *another?*

The magistrate, in giving judgment, observed, that he had no discretion in the case. The Act absolutely required that, " If any person shall use any furnace which shall not be constructed so as to *consume or burn its own smoke*, any person so offending, being *the owner or occupier of the premises*, shall pay a sum not more than five pounds, nor less than forty shillings." Under these circumstances he was not called on to show how furnaces should be constructed. The nuisance was proved to exist, and the penalty must be inflicted.

Now, although the law visited the miller in the first instance, had he brought an action against the maker of the steam-engine and boiler he would have been entitled to recover the amount of the penalty inflicted. This view of the subject was confirmed by the opinion of the stipendiary magistrate in a more recent case, where it was clearly proved that a boiler and its furnaces were imperfect and ill-constructed. In that case, the magistrate observed, that " The boiler and its furnace being defective was not the fault of the *owners* of the steamboat which created the nuisance; that they had given directions for a proper instrument, and went to a respectable tradesman to supply them; and, if they chose, they might follow it up, *and recover, in another court, from the maker of the boiler*, the loss they had sustained." Until, however, some more summary means of redress be supplied, such a proceeding can, practically, be of no avail.

Here, however, the finger of the law pointed in the right direction. The boiler was a machine that could not be worked without creating an indictable offence. Not only legally, but morally, the maker was then liable for the imperfection of the machine he had supplied. If he was incompetent, he alone should be held accountable. Let the engineer be bound to give a reasonable trial of the boiler, as he does of the engine. Let him work both for any specific period in testing their efficiency, one proof of which should be, that *no smoke nuisance be created.* Let such be proved before the inspector, and then any neglect or subsequent mismanagement by which a nuisance should be created, would necessarily and rightly lay at the door of the *owner* or his *stoker.* Let this be required, and the evil will soon cease to exist. In truth, there is no other means of suppressing it, inasmuch as the mere miller, or manufacturer, or uninformed public, never can be taught, nor expected to be acquainted, either with the laws of combustion, or the mode of carrying them into practice.

And see the strict justice of such an arrangement. It is not only the duty, but is peculiarly within the province and power of the engineer,—an educated, professional man,—to understand and reduce to practice what belongs to the use of the fuel he employs as regards its application in the generating steam for the purposes of the engine he contracts to make. Without this knowledge, the efficiency of his work must remain a matter of chance. He makes his calculations as to what is required for his engine,—so should he be equally attentive in respect to the *boiler*. It cannot surely be the province of the miller or the silk, cotton, or other manufacturer to teach the engineer how to construct the apparatus he undertakes to make. If, however, the latter will not make himself master of his business he must be responsible for the consequence of his inexperience. He is not justified in experimenting on the construction of a boiler (as many do), and then throwing the responsibility of its failure on others.

It will not now suffice for an engineer to allege that the means of effecting the combustion of coal, or the gas from coal, without smoke, is still among the undiscovered mysteries of nature. This is not the fact. It is directly the reverse of the fact. The subject, in all its details, is thoroughly understood and reduced to practice. If, however, those whose peculiar duty it is to study these truths of science

will continue to construct boilers and furnaces by arbitrary rules, and with relation to *mechanical*, in defiance of *chemical* laws, they should be held responsible for their short comings, as would the unqualified or ignorant surgeon who should undertake to amputate a limb, or perform any other surgical operation. In practice, it is too often the case, that principle or system is altogether set at nought. We see the furnaces, flues, and other parts of the boilers, even from the *same maker*, so utterly *at variance with each other*, that it is manifest the designer had no conception of a *true system* when studying their arrangements and construction. To what, then, is this discreditable state of things in this important department attributable? Manifestly to *the neglect of those chemical, or rather natural laws by which the process of combustion is governed.* Until those laws are studied, and the principles on which they may be reduced to practice be understood, engineers must continue in a continual sea of errors, and be prepared to incur the penalties of their unpreparedness.

With the view of aiding in this desirable work of abating the nuisance, the following draught of an amended Act is here offered for public consideration, the existing act being followed except so far as it was necessary to alter it in giving it a correct and practical application; and with the addition of the remedial measure:

EXISTING ACT.	AMENDED ACT.
16th and 17 Victoria, Ch. 178. *An Act to abate the Nuisance arising from the Smoke of Furnaces in the Metropolis and from Steam Vessels above London-bridge:*	*An Act to abate the Nuisance arising from the Smoke of Furnaces.*
Whereas it is expedient to abate the Nuisance arising from the smoke of furnaces in the Metropolis and from steam-vessels above *London-bridge*; Be it therefore enacted by the Queen's most Excellent Majesty, by and with the advice and consent of the Lords Spiritual and Temporal, and Commons, in this present Parliament assembled, and by the authority of the same, as follows:—	Whereas it is expedient to abate the nuisance arising from the smoke of furnaces, Be it therefore enacted by, &c.
1. From and after the first day of *August*, one thousand eight hundred and fifty-four, every furnace employed or to be employed in the Metropolis in the working of engines by steam, and every furnace employed or to be employed in any mill, factory, printing-house, dye-house, iron foundry, glasshouse, distillery, brewhouse, sugar-refinery, bakehouse, gasworks, water-works, or other buildings used for the purpose of trade or manufacture within the Metropolis (although a steam-engine be not used or employed therein), shall in all cases be constructed or altered so as to consume or burn the smoke arising from such furnace; and if any person shall, after the first day of *August*, one thousand eight hundred and fifty-four, within the Metropolis, use any such furnace which shall not be constructed so as to consume or burn its own smoke, or shall so negligently use any such furnace as that the smoke arising therefrom shall not be effectually consumed or burnt, or shall carry on any trade or business which shall occasion any noxious or offensive effluvia, or otherwise annoy the neighbourhood or inhabitants, without using the best practicable means for preventing or counteracting such smoke or other annoyance, every person so offending, being the owner or occupier of the premises, or being a foreman or other person employed by such owner or occupier, shall, upon a summary conviction for such offence before any Justice or Justices, forfeit and pay a sum not more than five pounds nor less than forty shillings, and upon a second conviction for such offence the sum of ten pounds, and for each subsequent conviction a sum double the amount of the penalty imposed for the last preceding conviction: provided always, that nothing in this Act shall extend or apply to any glass works or pottery works established and existing within the Metropolis before the passing of this Act, with the exception, however, of all steam-engine furnaces and slip kiln furnaces employed in and belonging to such works respectively, to which furnaces the provisions of this Act shall extend and apply.	1. From and after the passing of this Act, every furnace employed in any mill, factory, or other building used for the purposes of trade or manufacture, or in connexion with any steam-engine, or in any steam-vessel plying on any navigable river or canal, shall, in all cases, be constructed or altered so to consume or effect the combustion of the fuel employed, and the combustible gases arising therefrom, that there shall be no objectionable or offensive issue of smoke from the chimney of the same. And if any person shall hereafter use any such furnace which shall not be so constructed, or shall negligently use any such furnace so as to produce such an issue of smoke as to injure or annoy the neighbourhood or inhabitants thereof without using the best practicable means for preventing or counteracting the same, every person so offending being the occupier or owner of the premises, or being a foreman or other person employed by such owner or occupier, shall, upon a summary conviction, &c. &c.
2. From and after the first day of *August*, one thousand eight hundred and fifty-four, every steam-engine and furnace used in the working of any steam vessel on the River Thames, above *London-bridge*, shall be constructed so as to consume the smoke arising from such engine and furnace; and if after the said first day of *August*, one thousand eight hundred and fifty-four, any steam-engine or furnace by which any steam vessel shall be worked while the same shall be above London-bridge, shall not be constructed so as to consume or burn its own smoke, or such steam-engine or furnace which shall be so constructed shall be wilfully or negligently used so that the smoke arising therefrom shall not be effectually consumed or burnt, the owner or master or other person having charge of such vessel shall, on a summary conviction for such offence before any Justice or Justices, forfeit and pay any sum not greater than five pounds nor less than forty shillings; and upon a second conviction for such offence, a sum of ten pounds; and upon every other subsequent conviction for such offence, a sum double the amount of the penalty imposed for the last preceding conviction.	2. Provided always that the words "consume or effect the combustion of the fuel and the combustible gases," shall not be held to mean the combustion of all the said fuel or gases, and that the Justice or Justices before whom the person shall be summoned, may remit the penalties enacted by this Act, if on the evidence of two or more professional engineers or other competent witnesses, such person shall be proved to have constructed or altered his furnaces so as to consume, or cause the combustion, as far as may be practicable, of the fuel used therein, and the combustible gases arising therefrom, and has carefully attended to the same, and consumed or caused the combustion as far as possible of the fuel employed, and the gases arising therefrom.
3. Provided always, that the words "consume or burn the smoke" shall not be held in all cases to mean "consume or	3. Provided always that in the case of boilers or furnaces which shall have been constructed after the passing of this

EXISTING ACT.	AMENDED ACT.
burn all the smoke," and that the Justice or Justices before whom any person shall be summoned may remit the penalties enacted by this Act, if he or they shall be of opinion that such person has so constructed or altered his furnace as to consume or burn as far as possible all the smoke arising from such furnace, and has carefully attended to the same, and consumed or burned as far as possible the smoke arising from such furnace.	Act, and from which any smoke may have arisen to the injury or annoyance of the neighbourhood, and by reason of which any penalty may have been incurred and inflicted in pursuance of this Act, the owner or occupier of such premises, or of such furnace or boiler, shall be entitled to sue for, and recover the amount of, such penalties so inflicted, by civil process in any County Court, from the engineer, maker, or other person who shall have provided or made such boilèr or furnace.
4. If the owner or occupier of any premises, or the commander of any steam vessel to which the provisions of this Act shall apply, shall refuse to allow their premises or steam vessels to be inspected by a person duly authorised by the Commissioners of police for that purpose, it shall be lawful for any constable authorised by warrant under the hand of one of her Majesty's principal Secretaries of State, or (in the Metropolitan police district) by the order in writing of the Commissioners of the police of the Metropolis, or (in the City of *London* or Liberties thereof) by the order in writing of the Com-	4. Provided always that if such engineer or maker of such boiler or furnace shall prove that a reasonable trial of such boiler or furnace and the working of the same, shall have been made, and that during such trial in the presence of the owner or occupier of the premises, or other person authorised by him, no smoke or annoyance as above mentioned had issued from the chimney of the same, or any indictable nuisance had been created: in such case, such engineer, maker, or other persons shall no longer be held responsible or liable for any nuisance arising from such boiler or furnace or other work.

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missioner of Police of the said City and Liberties, with or without any assistant, to enter into and upon any building or premises in the Metropolis in which any furnace may be, or in which such noxious trade or business may be carried on, or into any steam vessel on the river *Thames* between *London-bridge* and *Richmond-bridge*, and to examine into the construction of such furnace, into the manner of carrying on such trade or business, or into the construction of the steam engine and furnace by which such vessel shall be worked: and any person obstructing any such constable or his assistant in the execution of any such warrant or order shall, upon a summary conviction for such offence before any Justice or Justices, forfeit and pay any sum not exceeding twenty pounds.

5. Provided always, that no information shall be laid against any person for the recovery of any penalty under this Act, except by the authority of one of her Majesty's principal Secretaries of State, or in the Metropolitan police district by the Commissioners of police of the Metropolis, or in the City of London or Liberties thereof by the Commissioner of police of the said City and Liberties respectively, acting under the orders and directions of such Secretary of State.

6. In this Act, the expression "the Metropolis" shall have the same meaning and construction as is assigned to such expression for the purposes of the Act of the last session of Parliament, chapter eighty-five, "To amend the Laws concerning the Burial of the Dead in the Metropolis."

7. Nothing in this Act shall be held to alter or repeal any of the provisions of the City of *London* Sewers Act, 1851, or of the *Whitechapel* Improvement Act, 1853.

8. All penalties by this Act imposed shall be recoverable according to the provisions of the Act of the twelfth year of her present Majesty, chapter forty-three.

THE END.

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